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MEASUREMENTS OF BEND FLOW HYDRAULICS ON THE FALL RIVER AT LOW STAGE

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WRFSL PROJECT REPORT NO. 83 - 9P

WATER RESOURCE FIELD SUPPORT LABORATORY
NATIONAL PARK SERVICE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

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Director
Water Resources Field Support Laboratory
National Park Service
107C Natural Resources
Colorado State University
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MEASUREMENTS OF BEND FLOW HYDRAULICS ON THE FALL RIVER AT LOW STAGE

WRFSL Project Report No. 83-9P

Submitted to:

Water Resources Field Support Laboratory
Fort Collins, Colorado 80523

by

Colin R. Thorne, Samira Rais, Lyle W. Zevenbergen,
Jeff B. Bradley and Pierre Y. Julien

Department of Civil Engineering
Colorado State University

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National Park Service
Water Resources Field Support Laboratory
107C Natural Resources
Colorado State University
Fort Collins, Colorado 80523

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
FIELD SITE	1
INSTRUMENTATION	3
FIELD DATA	5
Channel Planform	5
Water Surface Topography	7
Bed Topography	9
Bedforms	11
Bed Material Size Distributions	13
Bedload Transport Rate	26
Two-Dimensional Velocities	27
CONCLUSIONS	47
ACKNOWLEDGEMENTS	48

LIST OF FIGURES

Figure		Page
1	Field Study Area: Fall River at Horseshoe Park in Rocky Mountain National Park	2
2	Instrumentation Used to Make x and y Velocity Measurements	4
3	Measurement Reach on Fall River, 24-27th August 1983 . .	6
4	Water Surface Topography in Study Reach	8
5	Bed Topography in Study Reach	10
6	Bedforms in Study Reach	12
7	Size-Frequency Curves for Bed Material in Study Reach	16
8	Distribution of Median Bed Material Size in Study Reach	25
9	Primary Isovels and Secondary Velocities at Sections 1 to 7	38
10	Long Stream and Cross Stream Velocities at Section 0 and 8	45

LIST OF TABLES

Table		Page
1	Channel Planform Parameters	5
2	Bed Material Size Distributions by Dry Sieving	14
3	Angles of Reorientation of Sections	27
4	x-y and Primary-Secondary Velocities for Sections 1 to 7	28
5	x-y Velocities for Sections 0 and 8	36

INTRODUCTION

The purpose of this report is to record field measurements of bend flow hydraulics and sediment characteristics made at comparatively low flow on the Fall River, Rocky Mountain National Park.

These data are significant because there is a dearth of information on the distributions of primary and secondary velocities, boundary shear stress and sediment movement in channel bends, in natural rivers. These data are required to apply, test and verify the increasing number of bend flow models being produced both in the USA and abroad.

To make up a hopefully, complete data set, measurements were made by a team of researchers over a two day period during which the flow was steady. Measurements consisted of, channel planform mapping, water surface and bed topography mapping, sketching of bedforms, sampling and sieve analysis of bed material, estimation of total bedload transport rate, and measurement of long stream and cross stream velocity at 9 sections. The complete data are presented in this report in that order. This is important because it is not possible to publish the data owing to the restricted space available in professional journals. It is the authors' intention that these data be available for use by interested researchers and it is to this end that this report is being produced.

FIELD SITE

The field site is on the Fall River at Horseshoe Park in Rocky Mountain National Park (Fig. 1). This reach of river was heavily impacted by the Lawn Lake Dam Failure on July 15, 1982. As a result of the dam failure, sediment supply to the river has been vastly increased and the stability of the channel has been reduced. Prior to the failure

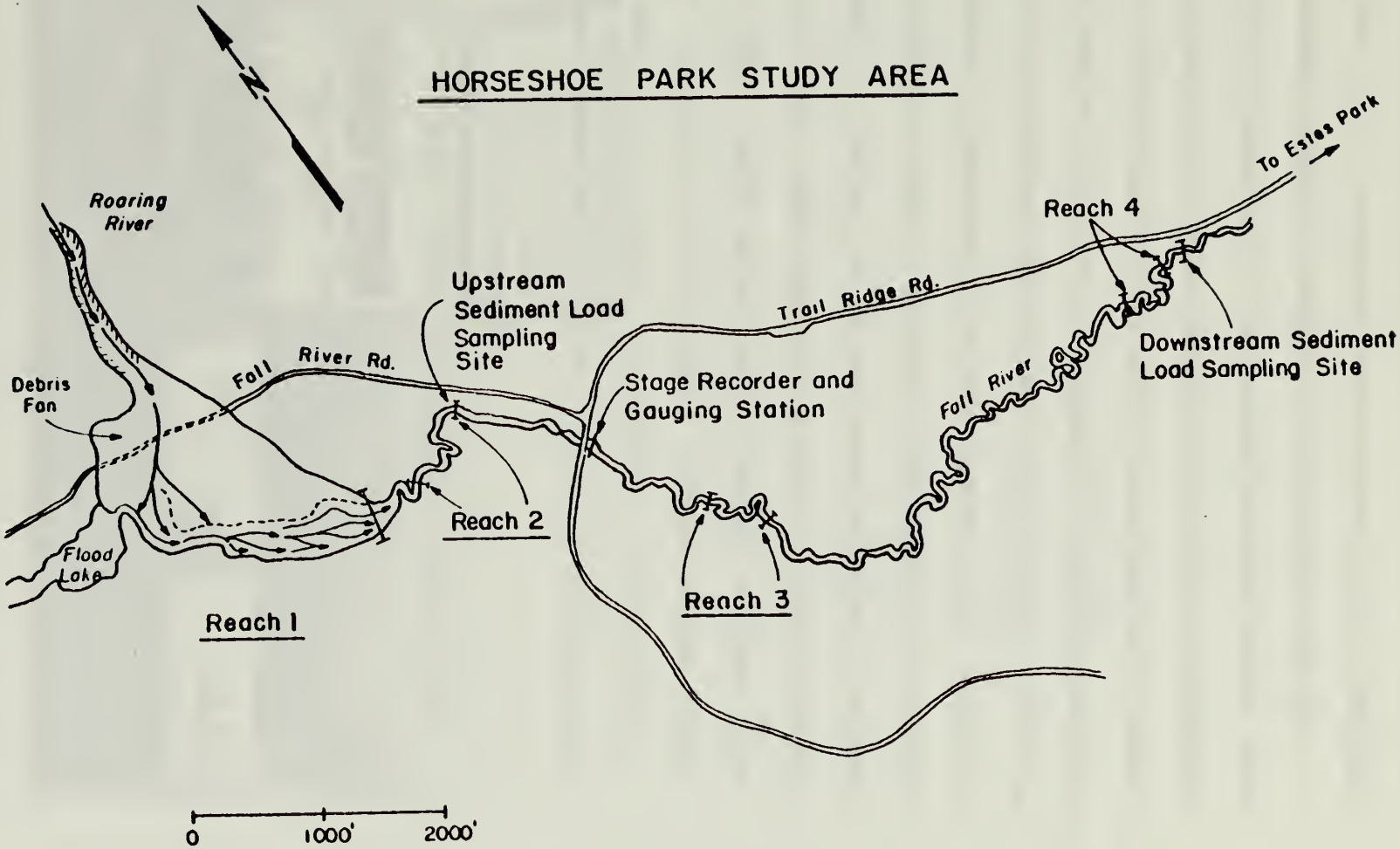


Figure 1. Field Study Area at Horseshoe Park in Rocky Moutain National Park

the study reach had an immobile gravel and cobble bed. Now it has a sand bed which is mobile even at low flow.

In the study reach the channel is highly sinuous (sinuosity 2.2) with stable banks of meander belt silts and clays strongly bound by vegetation. The river's hydrograph is entirely dominated by snowmelt runoff. The peak annual discharge is aroung 8.4 m^3/s (300 cfs). This produces overbank flow, bankfull capacity being of the order of 5.7 m^3/s (200 cfs). On the days of measurement discharge was steady at 1.7 m^3/s (60 cfs). The channel slope is approximately 1 percent and the bed material is coarse sand overlying a coarse substrate of gravel and cobbles. The sand moves mostly as bedload in ripples and dunes. Suspended load is usually low except when valley wall failures in a major upstream tributary, the Roaring River, input large amounts of glacial moraine material. This contains a rock flour component of fine silt which moves in suspension. Valley wall failures occur on slopes oversteepened by toe erosion during the dam break flood.

INSTRUMENTATION

The channel planform was mapped using a transit and staff. Distances were measured by tape. Water surface and bed topographies were established by levelling along 18 sections across the channel. These were located at the current metered sections plus 9 intermediate sections.

The bedforms were sketched by eye in reaches between the 9 metering sections, and the bedload was estimated from the rate of downstream movement of dunes in a straight reach just downstream of the experimental reach.

Velocity measurements were made using a Marsh-McBirney Model 511 two component electromagnetic current meter (Fig. 2). This simultaneously measures mutually perpendicular velocity components with an accuracy of ±3 mm/s (0.01 ft/sec). The sensor head is a one inch diameter sphere and the sensing volume is about double this size. This is small in comparison to the flow being measured in the Fall River. Each measurement was made for one minute. This was long enough to average out velocity fluctuations, but short enough to allow completion of the section in a reasonable time. Averaging was carried out as the measurements were made, by a Hewlett-Packard Data Logger. This consists of an HP-3421A Data Acquisition Unit and an HP-41CV calculator (Fig. 2). This system greatly reduces operator error in averaging the fluctuating velocity output, and provides fast and efficient data reduction and storage.

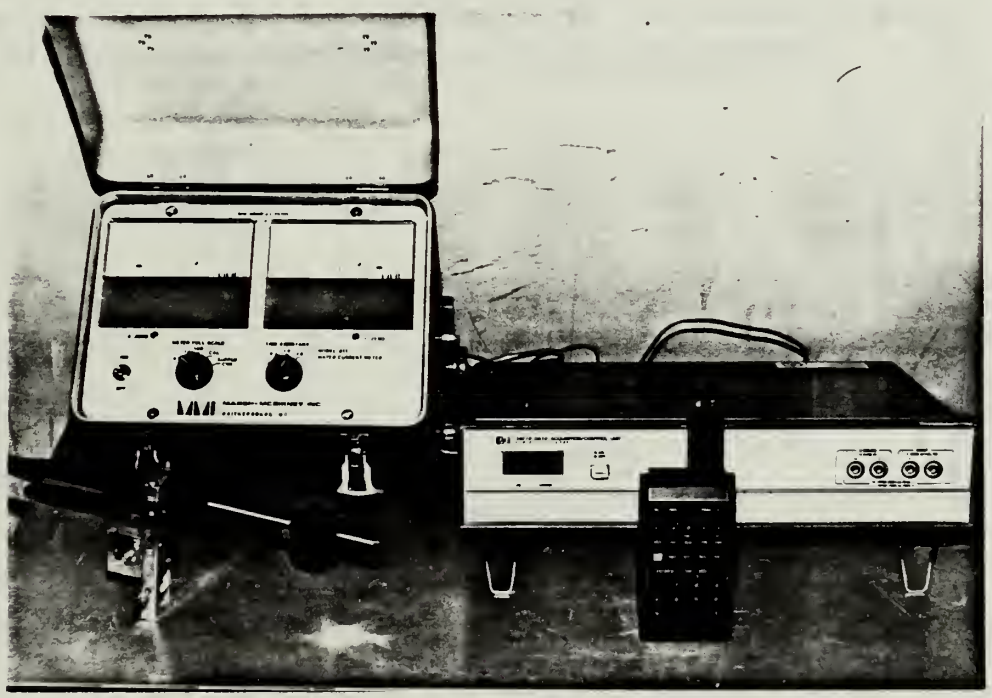


Figure 2. Instrumentation Used to Make Velocity Measurements

FIELD DATA

Channel Planform

The study reach consisted of consecutive meander bends in a sinuous reach of channel, reach 4 in Fig. 1. The bends were not quite symmetrical, but were in most respects similar. The channel planform and velocity sections are shown in Fig. 3. The planform geometric parameters are listed in Table 1.

The numbering of sections (0 to 8) was adopted for consistency with a paper* published on the basis of the velocity readings at the middle seven sections only (omitting the first and last sections). Consequently, sections 1 to 7 are those used in the paper, and 0 and 8 are the first and last ones.

Table 1. Channel Planform Parameters

Bend	Radius of curvature [m]	Arc angle [°]	Section number	Angle of orientation	Width [m]	Mean depth [m]
-	-	-	0	Upstream of bend A	10.00	0.30
			1	10	9.45	0.28
A	11.0	170	2	70	6.70	0.41
			3	140	7.30	0.31
Inflexion	-	-	4	-	8.50	0.31
			5	65	10.20	0.31
B	13.5	155	6	100	8.25	0.44
			7	120	5.80	0.40
-	-	-	8	155	10.40	0.30

*Thorne, C.R. and Rais, S. "Secondary Current Measurements in a Meandering River," In "Rivers '83," Proceedings of the ASCE Speciality Conference, New Orleans, October 1983, In Press.

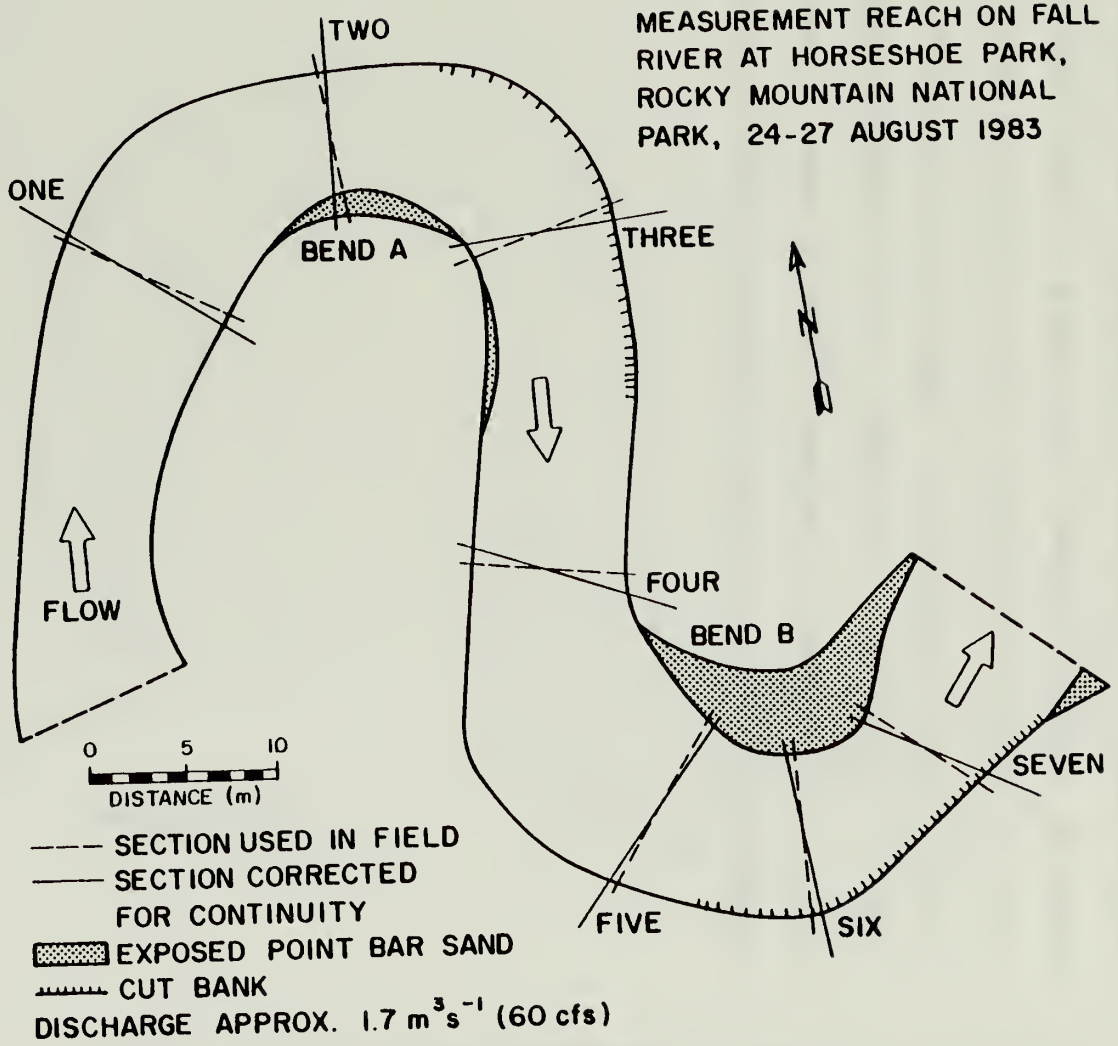


Figure 3. Measurement Reach on Fall River, 24-27th August 1983

Water Surface Topography

The water surface topography was surveyed by levelling along eighteen sections through the study reach. The water surface elevation at any point fluctuates through time, making a precise reading impossible. Consequently, the point elevations are subject to error. However, by making a large number of readings at each cross section and by measuring eighteen sections it was hoped to reduce these errors which should be randomly distributed. The consistency of the resulting pattern of water surface contours, suggests that errors were not too great (Fig. 4). Based on an assessment of the technique employed and on engineering judgement, a confidence limit of about ±15 mm (0.05 ft) is probably realistic for the water surface elevations at any point.

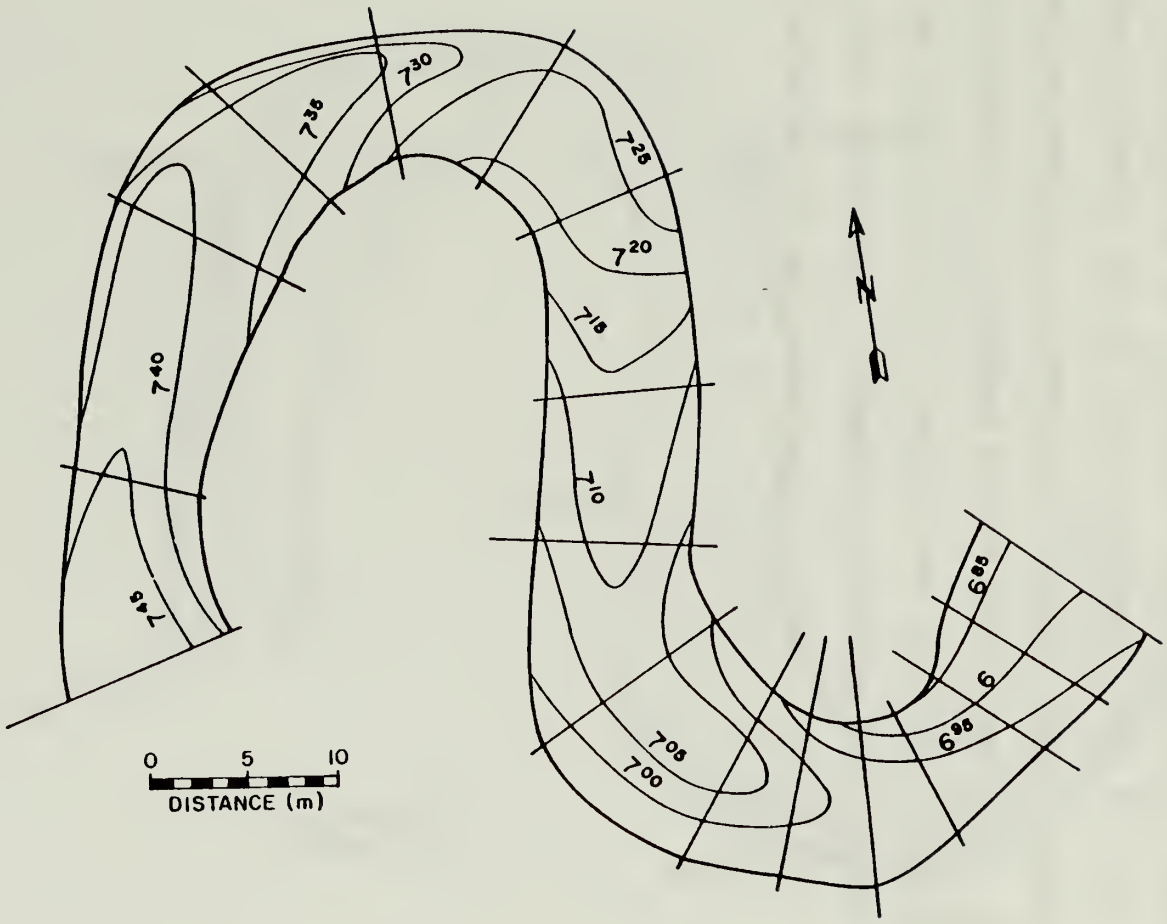


Figure 4. Water Surface Topography in Study Reach. Elevations are feet and hundredths of feet above an arbitrary datum.

Bed Topography

Bed topography was surveyed at the same time as the water surface topography. The bed elevation varies through time at a point due to the passage of bedforms. In taking the elevation it was attempted to always measure to mid-height on the bed form (if present) but this was difficult to do consistently, especially in the deep pools. Consequently, there is error associated with the bed elevation measurements. By making a large number of measurements at eighteen sections it was hoped to reduce these errors and the consistency of the bed elevation contours suggest that this was achieved (Fig. 5). Based on the technique employed and engineering judgement, a confidence limit of about ±5 cm (0.16 ft) is probably realistic for the bed elevation at any point.

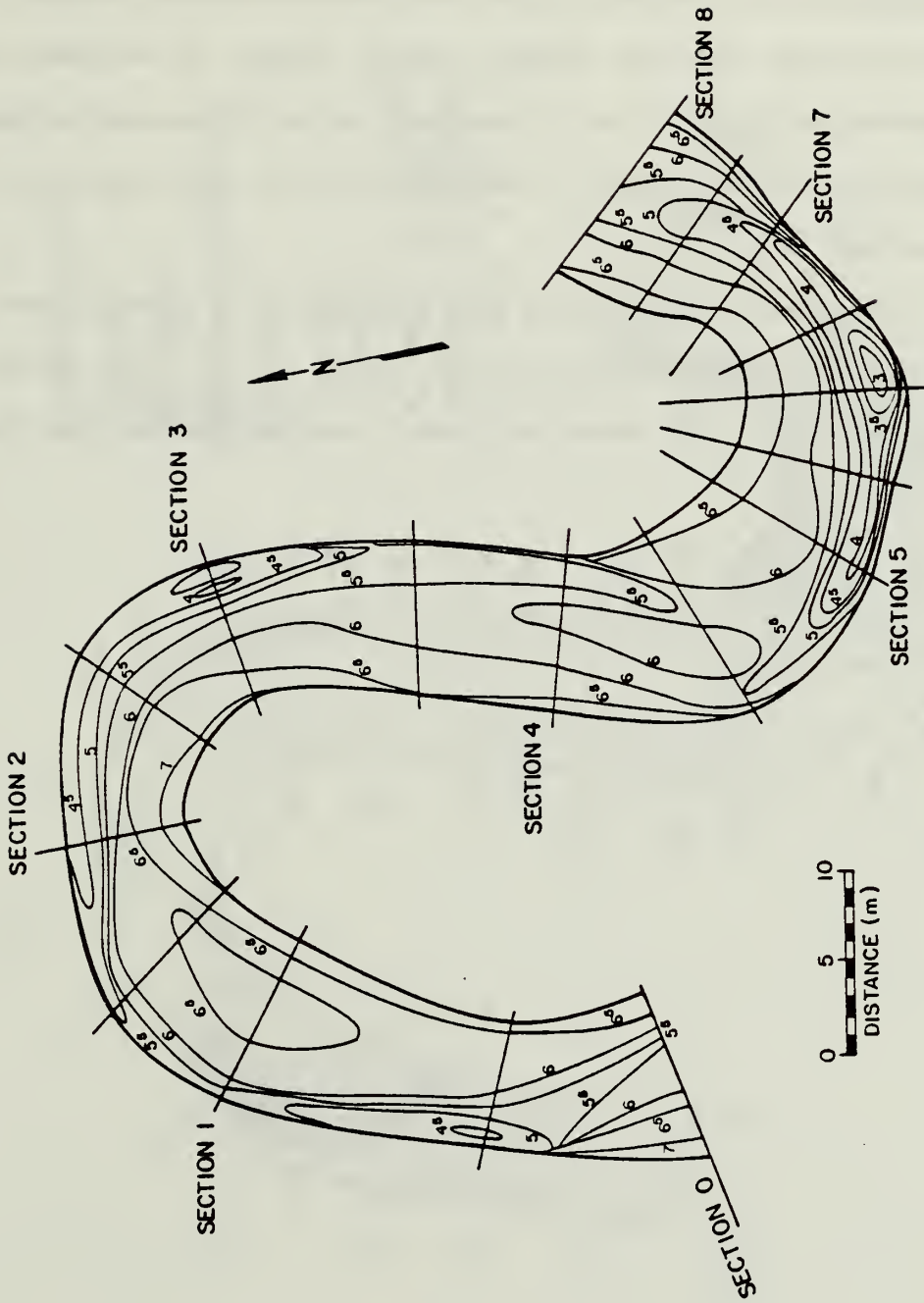


Figure 5. Bed Topography in Study Reach. Elevations are in feet and tenths of feet above the same arbitrary datum as the water surface topography map (Fig. 4).

Bedforms

The bedforms were sketched by eye whilst wading the channel. The suspended load was practically zero and the organic content very small, so that the bed was clearly visible except in the deep pools. The bedform map (Fig. 6) is a composite of the 16 reaches between surveyed sections. The bedform crests are shown superimposed on the bed contours.

The map is qualitative but should provide some guidance when using the quantitative data as to the nature of the local bedform and the orientation of the crests relative to the channel and the flow.

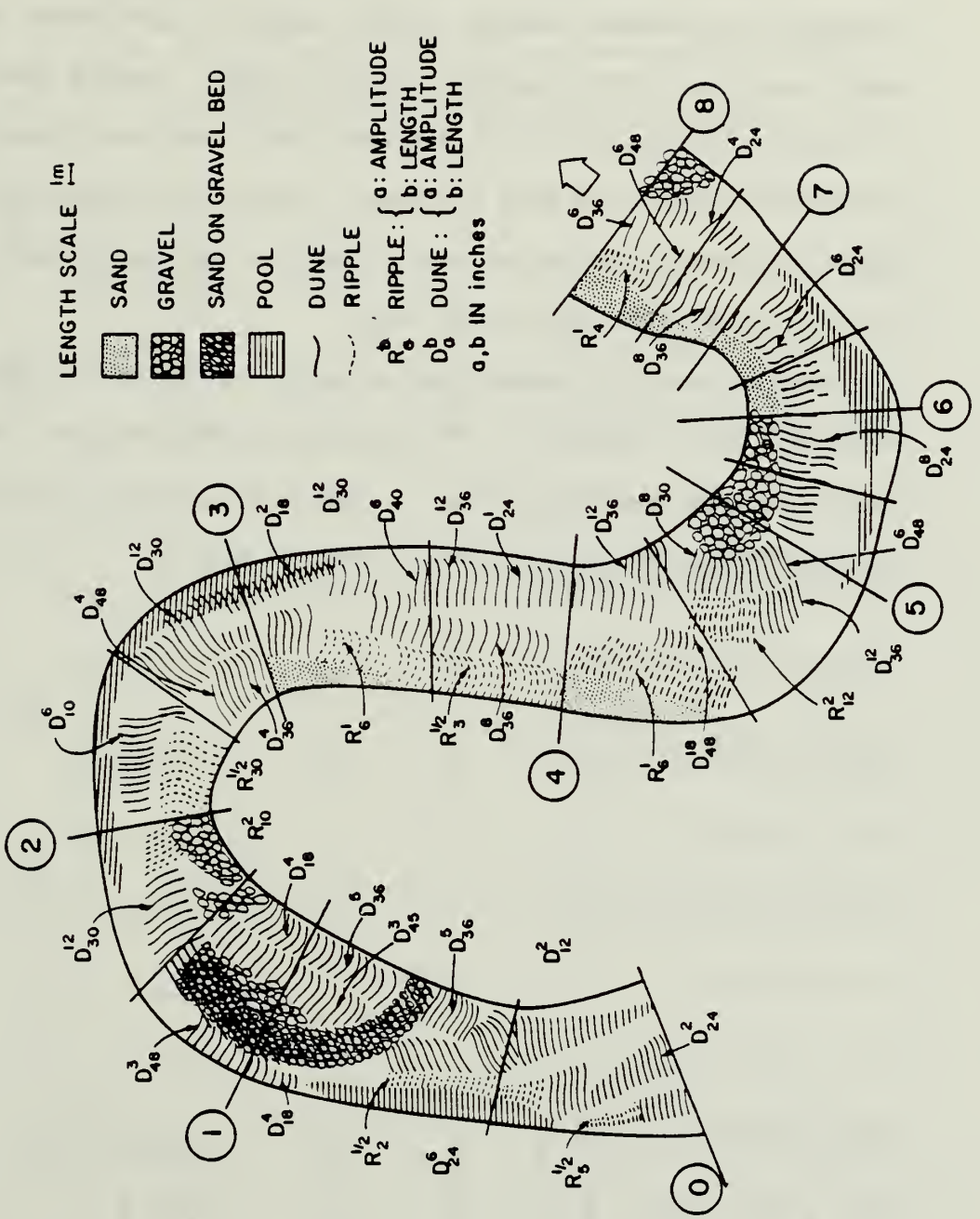


Figure 6. Bedforms in Study Reach

Bed Material Size Distributions

Bulk samples of bed material were collected at 5 points across each of the 9 current metered sections. The sampling points corresponded to: left bank, left-center channel, center channel, right-center channel and right bank being evenly spaced across the width. Samples were collected by scooping through the local bedform. The scoop was capped in situ at the bed to mitigate the loss of fines. However, as the bed material was almost exclusively medium to coarse sand and gravel, probably there was not much fines to be lost in any case.

Samples were dry sieved and recorded as percent by weight using standard sieve intervals. The size distributions are tabulated in Table 2 and are plotted in Fig. 7. The distribution of median diameter over the bed in the study reach is shown in Fig. 8.

Table 2. Bed Material Size Distributions

Section	Location	Weight before sieving	fall through		0.0049 ins 0.125 mm		0.0117 0.297		0.0234 0.595		0.0469 1.19		0.0937 2.38		0.187 4.76		0.375 9.52	
			g	%	g	%	g	%	g	%	g	%	g	%	g	%	g	%
0	left bank	428	6	1	117	27	234.5	55	64	15	6	1	0.5	0	0	0	0	0
0	left center	474	2	0	995	21	308	65	61.5	13	3	1	0	0	0	0	0	0
0	center	484	1	0	66	14	308.5	64	95	20	10	2	2.5	1	1	0	0	0
0	right center	729	0.5	0	17.5	2	236	32	298	41	134	18	34.5	5	8.5	1	0	0
0	right bank	791	1.5	0	15.5	2	203	26	399.5	51	15.8	20	13.5	2	0	0	0	0
0	left bank	1083	8	1	68.5	6	162	15	97.5	9	45.5	4	57	5	124.5	11	264	24
															3/4 ins			
															256	24		
1	left center	840	1	0	50.5	6	414	49	302	36	64.5	8	7.5	1	0.5	0	0	0
1	center	953.5	1.5	0	70	7	348.5	37	193	20	27	3	6.5	1	18.5	2	38	4
															3/4	ins		
															250.5	26		
1	right center	962	1.5	0	74.5	8	247	26	134	14	28.5	3	9.5	1	13.5	1	68	7
															3/4 ins			
															385.5	40		
2	right bank	855	1	0	23.5	3	274.5	32	411.5	48	131	15	12.5	1	1	0	0	0
2	left bank	473	1	0	44.5	9	285	60	117	25	23	5	2	0	0.5	0	0	0
2	left center	475	1	0	69	15	244.5	51	112.5	24	39	8	8	2	1	0	0	0
2	center	487.5	0.5	0	64.5	13	293.5	60	110	23	16.5	3	2	0	0.5	0	0	0
2	right center	504	1	0	25	5	158.5	31	211	42	94.5	19	13	3	1.5	0	0	0
2	right bank	502.5	5.5	1	72.4	14	295.5	59	122.5	24	6.5	1	0	0	0	0	0	0
3	left bank	370	2	1	26	7	123.5	33	175.5	47	37.5	10	5	1	0.5	0	0	0
3	left center	488	0.5	0	22.5	5	207	42	198.5	41	54	11	5.5	1	0	0	0	0
3	center	516	1	0	46	9	345.5	67	113	22	9.5	2	1	0	0	0	0	0
3	right center	504.5	1.5	0	73.5	15	228	45	158.5	31	38.5	8	4	1	0.5	0	0	0
3	right bank	508	1.5	0	89	18	297	58	106.5	21	13	3	1	0	0	0	0	0
4	left bank	359	0.5	0	5.5	2	79	22	154.4	43	88.5	25	25	7	6	2	0	0
4	left center	520	1	0	36	7	192.5	37	182	35	83	16	22.5	4	3	1	0	0
4	center	467	1	0	64	14	250	54	129	28	20	4	2	0	1	0	0	0
4	right center	468	1	0	60	13	259	55	130.5	28	16.5	4	1	0	0	0	0	0
4	right bank	486.5	3.5	0	122.5	25	281.5	58	74	15	4.5	1	0.5	0	0	0	0	0
4	left bank	545	2.5	0	26.5	5	94.5	17	163	30	145	27	44.5	8	18	3	51	9

Table 2. Continued.

Section	Location	Weight before sieving	fall through 0.0049 ins 0.125 mm		0.0117 0.297		0.0234 0.595		0.0469 1.19		0.0937 2.38		0.187 4.76		0.375 9.52	
			g	%	g	%	g	%	g	%	g	%	g	%	g	%
5	left center	513.5	1	0	28	5	195	38	220	43	62	12	7.5	1	0	0	0	
5	center	492.5	1	0	52	11	271.5	55	151.5	31	15.5	3	1	0	0	0	0	
5	right center	516	1.5	0	105	20	301.5	58	100	19	7.5	1	0.5	0	0	0	0	
5	right bank	653	9	1	278	43	331.6	51	33.5	5	1	0	0	0	0	0	0	
6	left bank	504	2	0	27	5	130.5	26	197.5	39	120.5	24	25	5	1.5	0	0	
6	left center	564.5	0.5	0	26	5	212	38	218	39	89.5	16	17	3	1.5	0	0	
6	center	546.5	2	0	47.5	9	247.5	45	208.5	38	36	7	4	1	1	0	0	
6	right center	466	2.5	1	58	12	279.5	60	113	24	12	3	1	0	0	0	0	
6	right bank	499	9	2	118.5	24	326.5	65	44.5	9	0.5	0	0	0	0	0	0	
7	left bank	498.5	2	0	34	7	169.5	34	214.5	43	71.5	14	6.5	1	0.5	0	0	
7	left center	533	1	0	40.5	8	225	42	210	39	52.5	10	4	1	0	0	0	
7	center	560.5	0.5	0	50	9	323	58	149	27	32	6	6	1	0	0	0	
7	right center	446.5	0.5	0	30.5	7	252.5	54	153	34	19	4	1	0	0	0	0	
7	right bank	446.5	0.5	0	8	2	119.5	27	216	48	75.5	17	22.5	5	45	1	0	
8	left bank	509.5	129	25	342.5	67	34.5	7	3	1	0.5	0	0	0	0	0	0	
8	left center	518	1.5	0	122	24	321.5	62	68.5	13	4	1	0.5	0	0	0	0	
8	center	527	1	0	47	9	260	49	164	31	49	10	5.5	1	0.5	0	0	
8	right center	500	0.5	0	16	3	209	42	242	48	29	6	3.5	1	0	0	0	
8	right bank	673.5	5	1	35.5	5	49.5	7	25.5	4	33	5	44.5	7	65.5	10	201	30
															3/4			
															214	31		

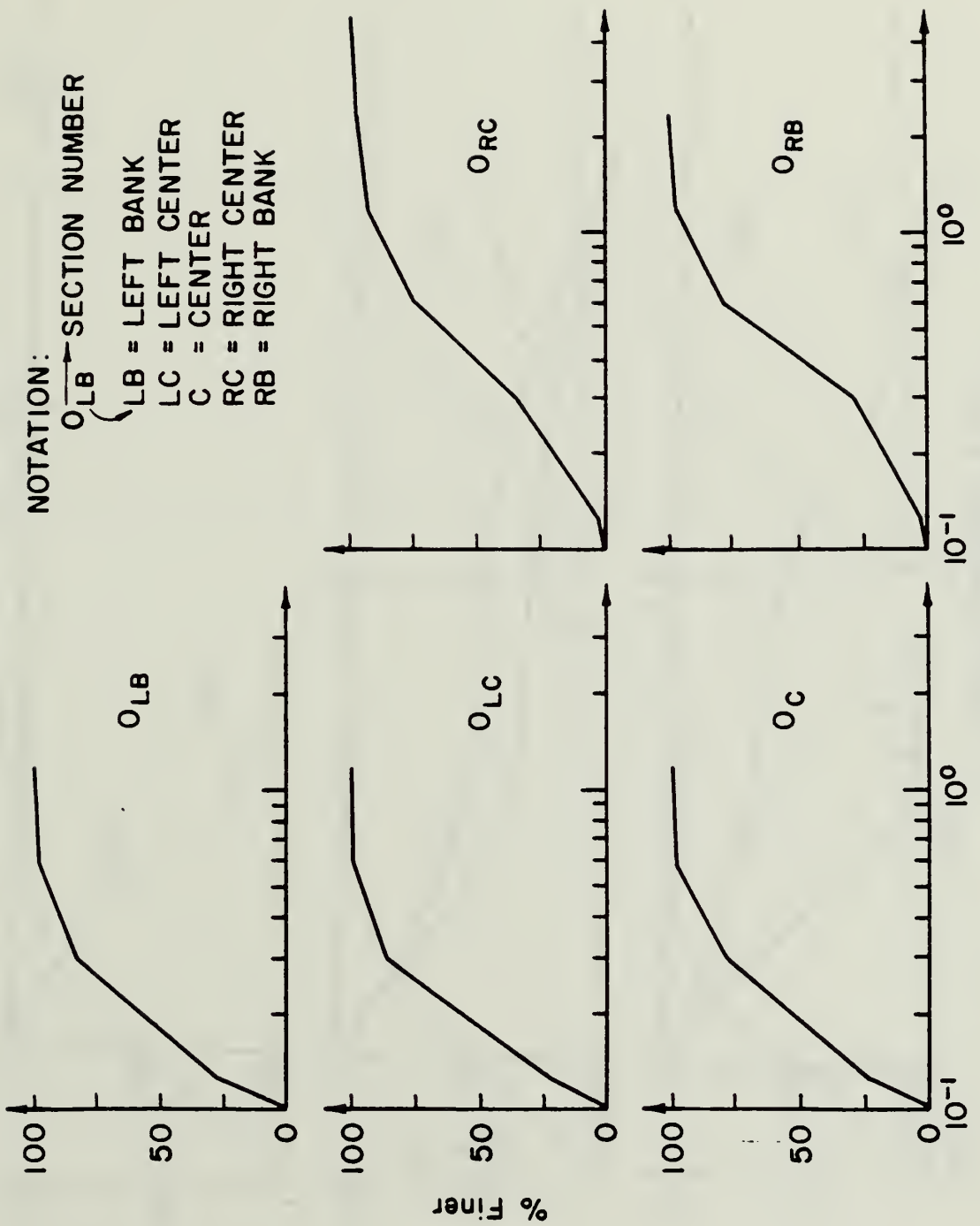
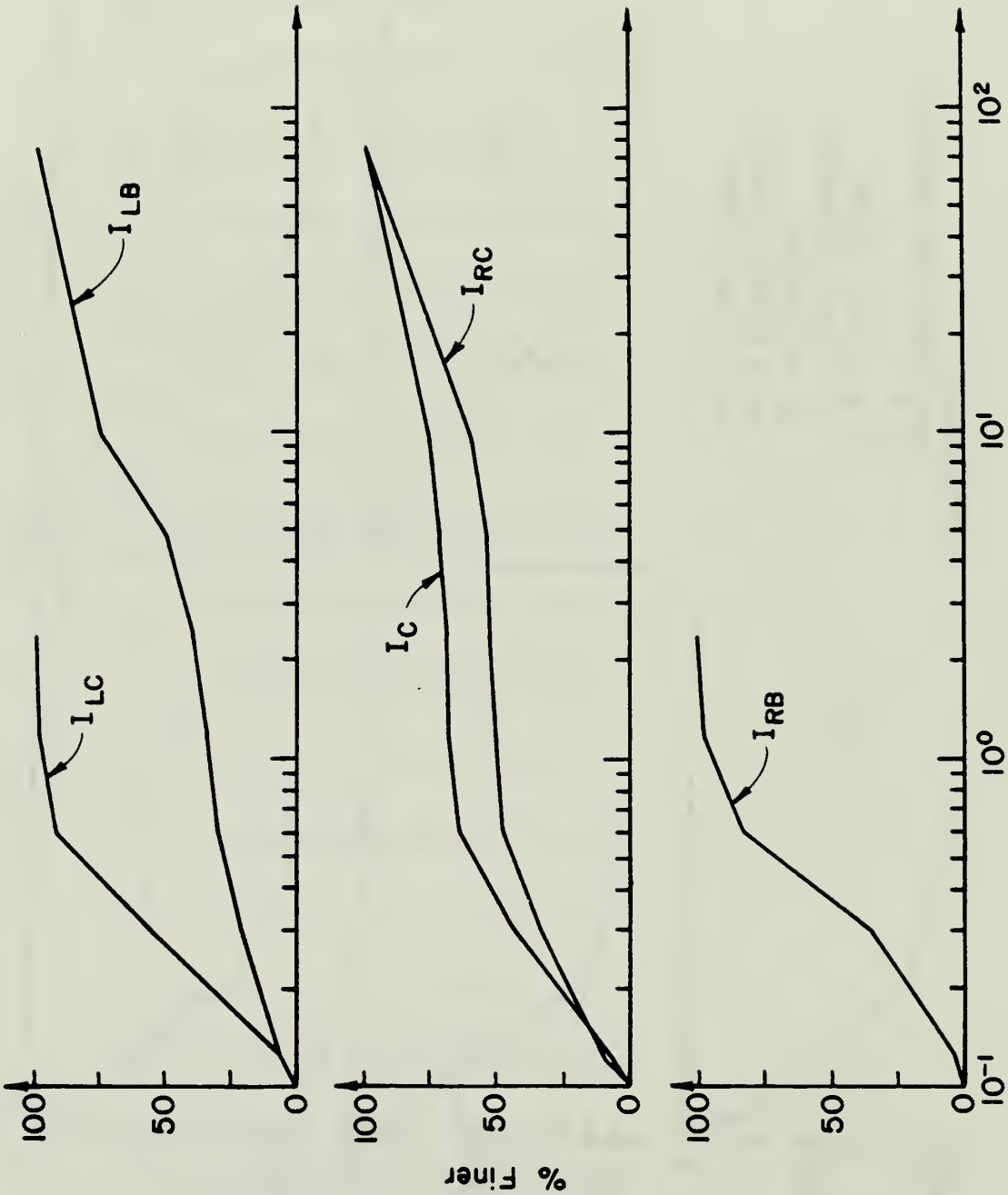


Figure 7. Size-Frequency Curves for Bed Material in Study Reach



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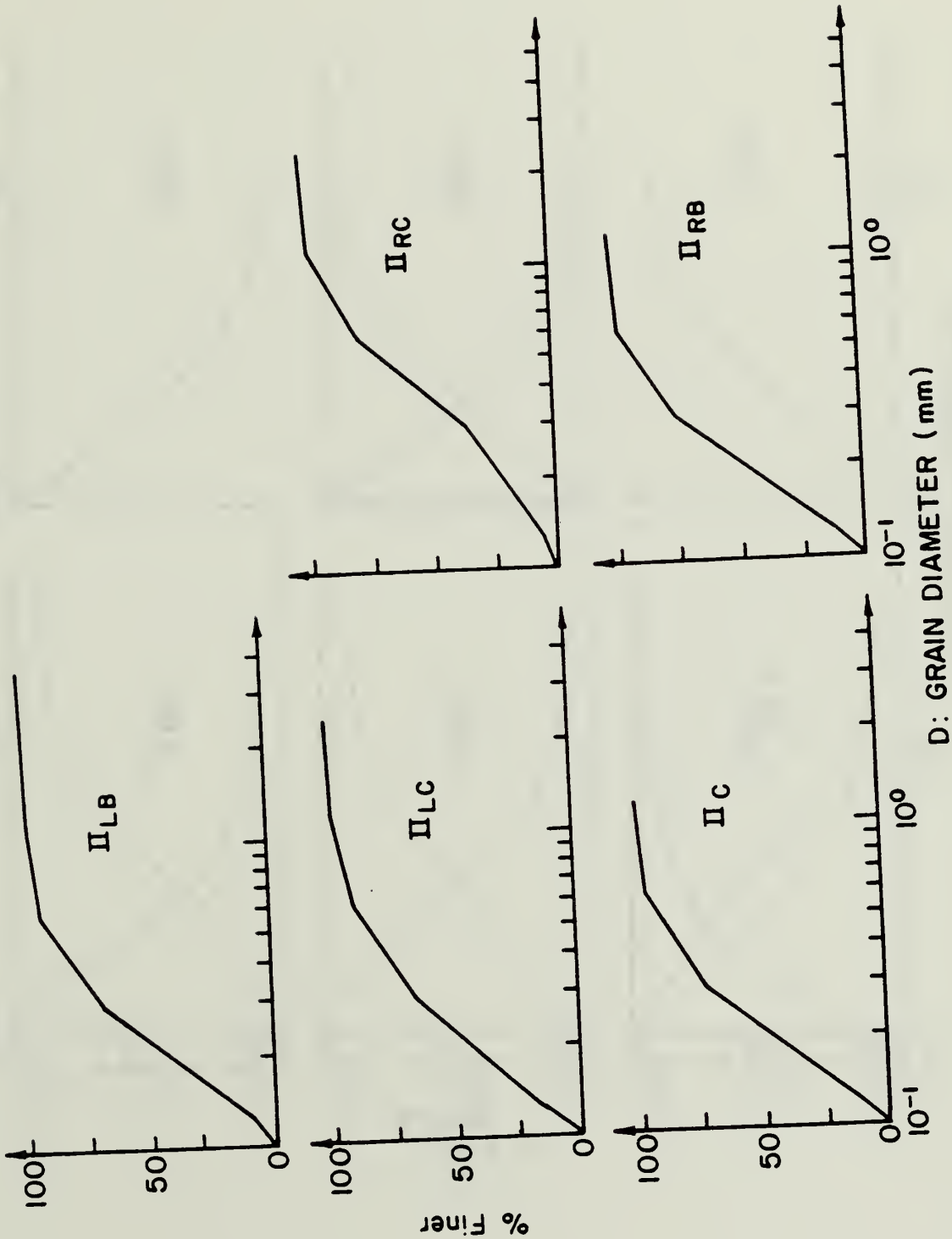

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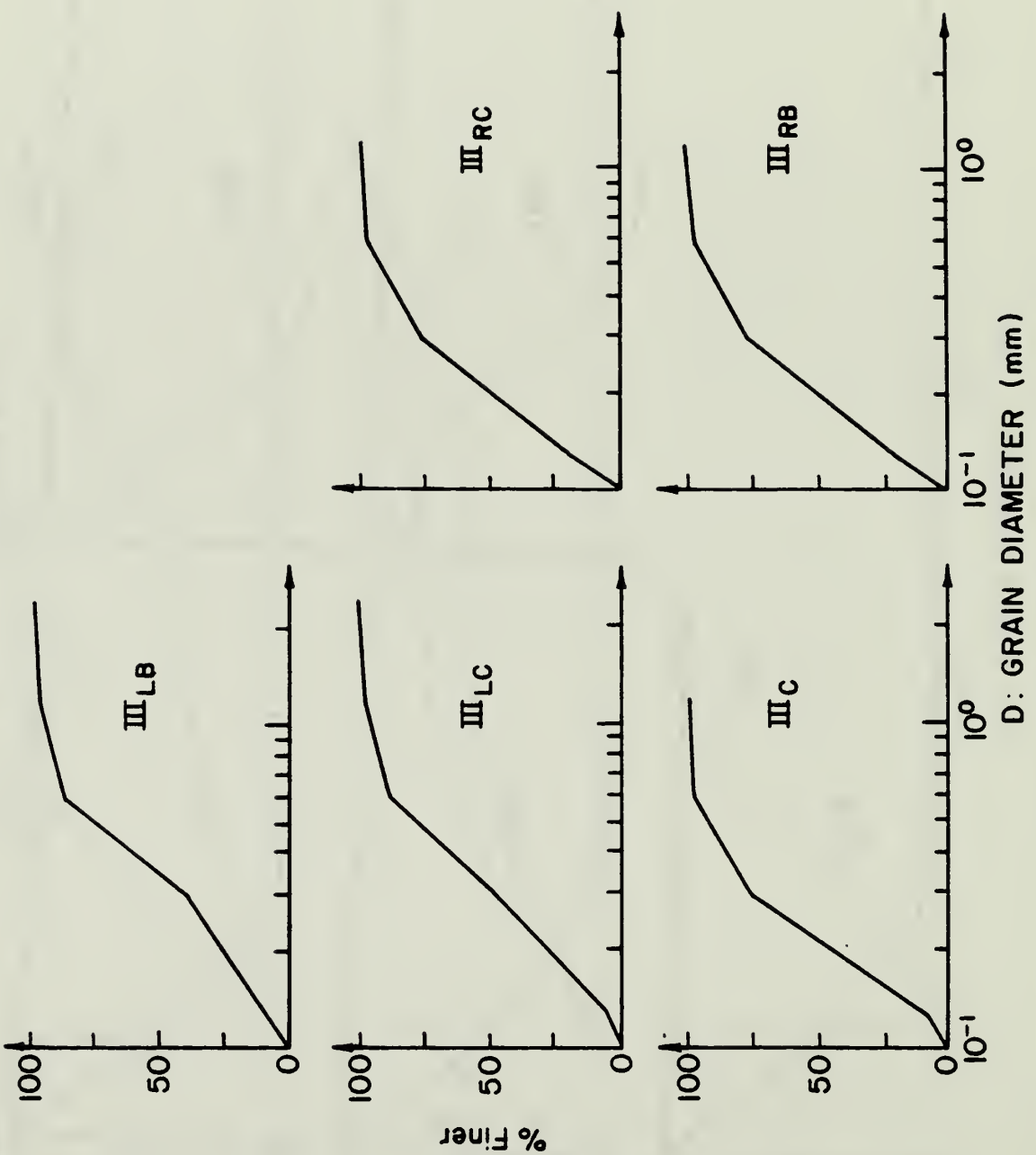

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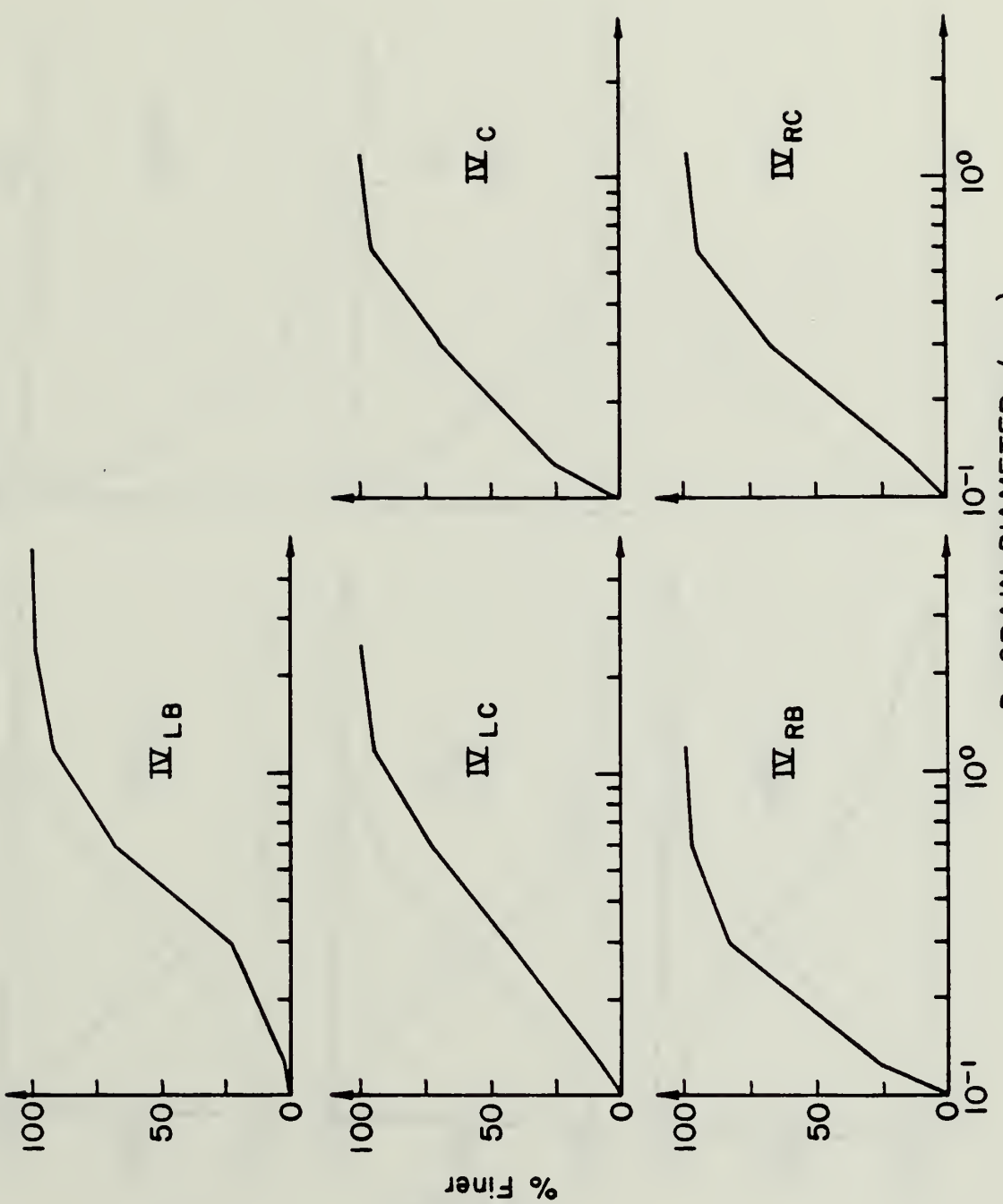

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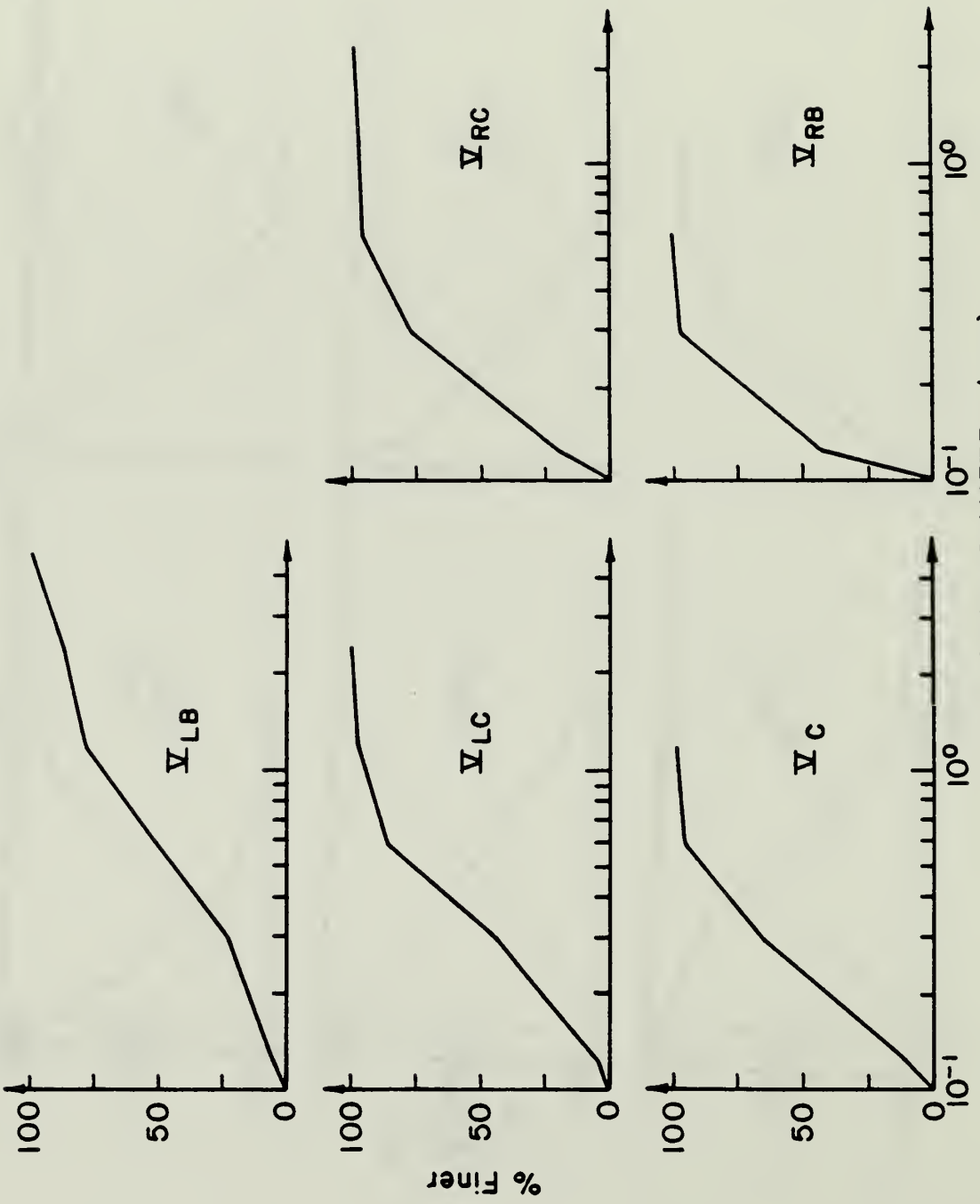

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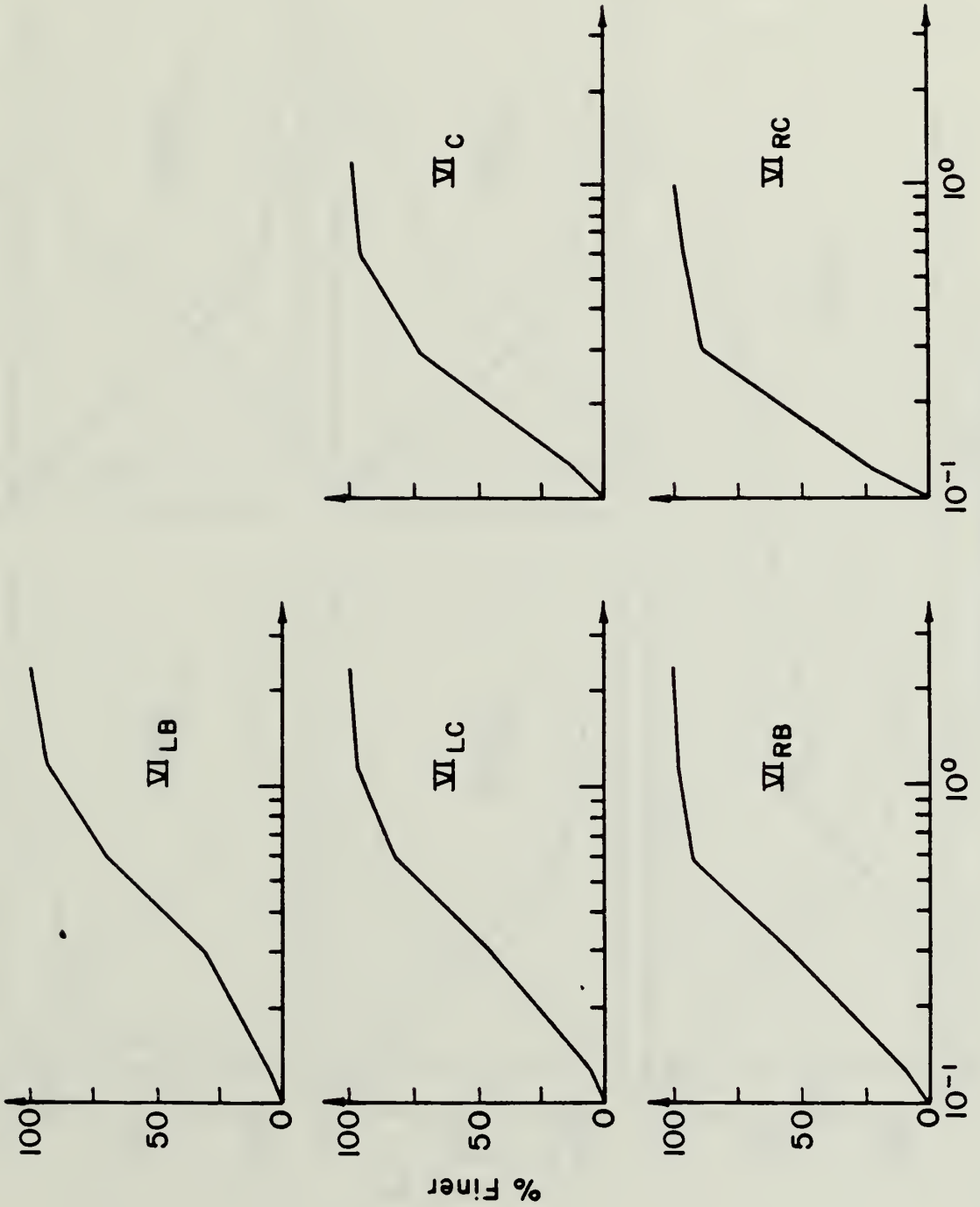

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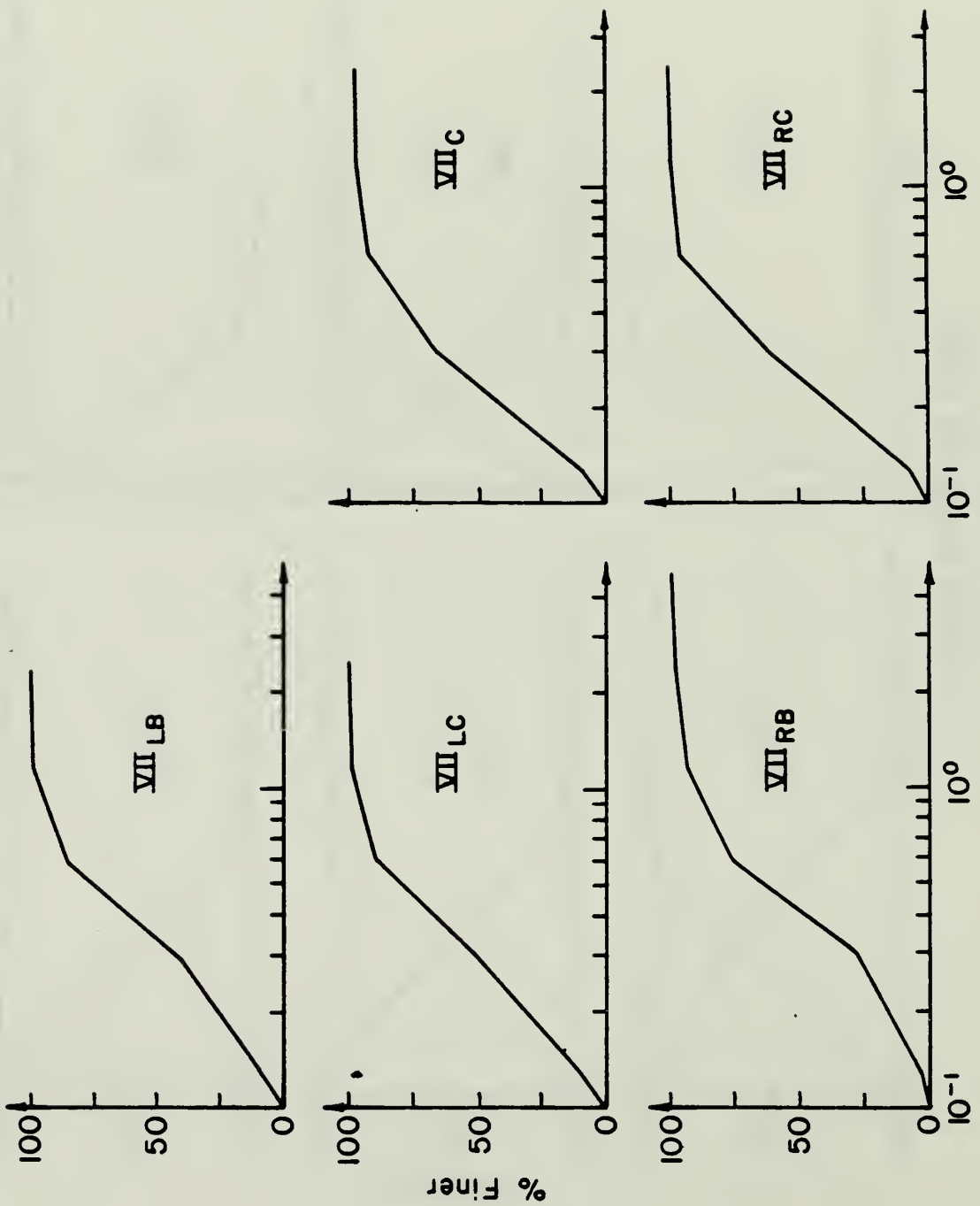

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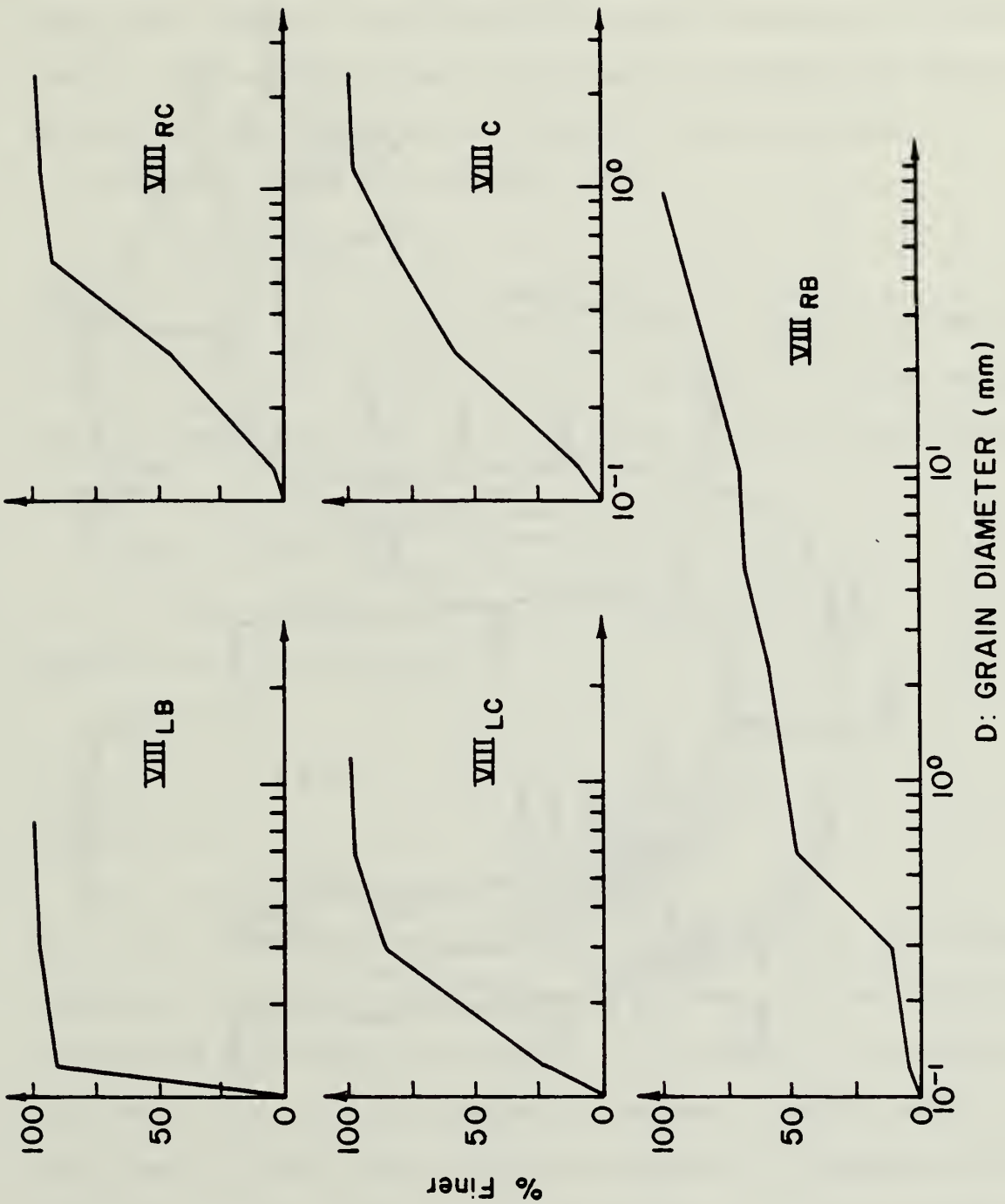

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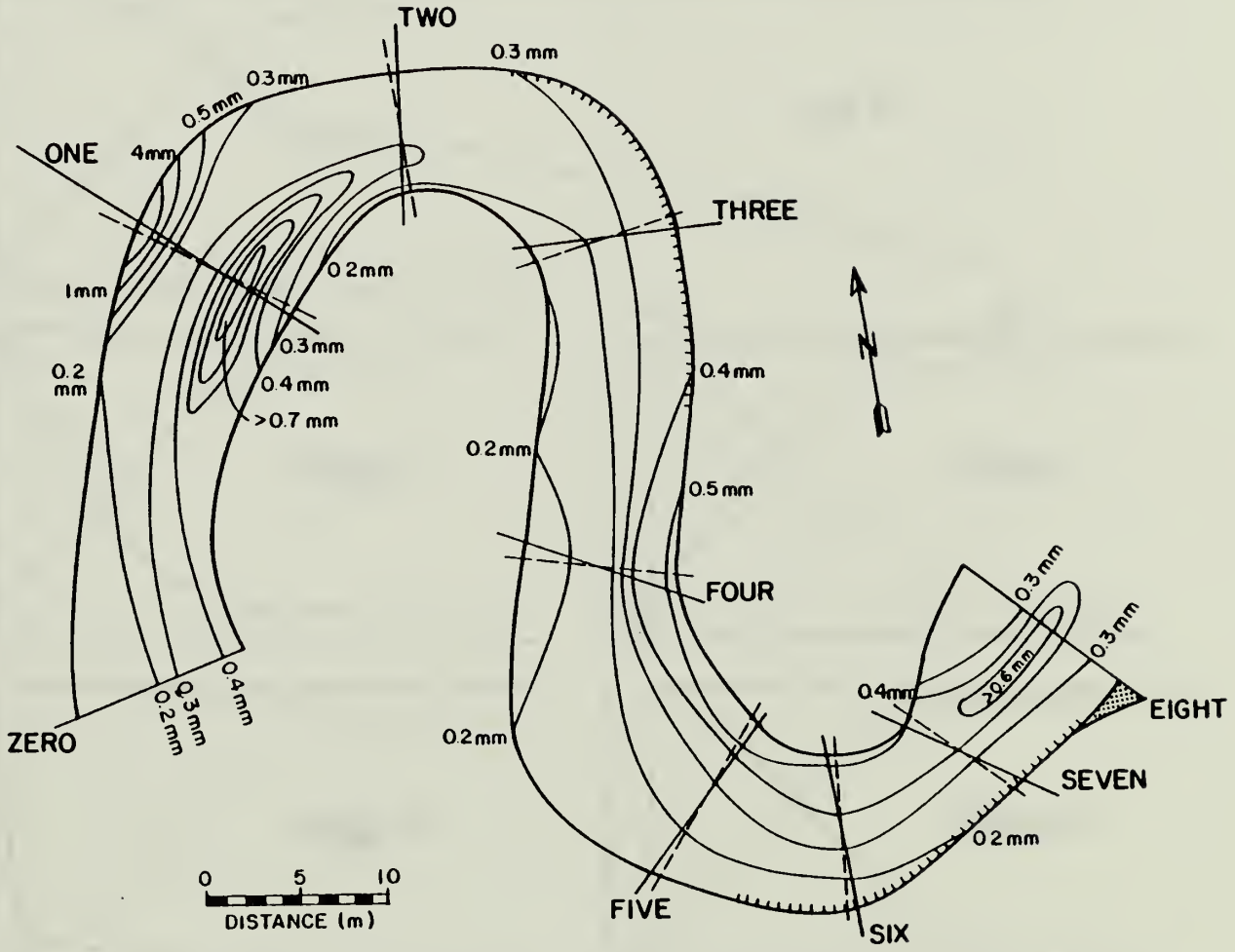

Figure 8. Distribution of Median Bed Material Size in Study Reach

Bedload Transport Rate

Bedload transport rate was estimated from the speed of downstream migration of a dune in a straight reach just downstream of the study reach. The technique was proposed by Simons, Richardson and Nordin (1965).* This method was used because there was insufficient man power and time available for bedload measurement by bedload sampling.

The transport rate was calculated from:

$$Q = (1 - \lambda)\, \bar{V}_d\, \frac{\bar{h}}{2}\, W$$

where Q is the bedoad transport rate, λ is the porosity of the bed material, $\bar{V}_d$ is the average velocity of the dune, $\bar{h}$ is the average amplitude of the dune, and W is the channel width over which the bed is active.

For the straight reach:

$$\bar{V}_d = 1.16 \text{ m/hr}, \quad \bar{h} = 0.11 \text{ m}, \quad \lambda = 0.36, \quad W = 6.5 \text{ m}$$

measured over a one-hour period.

This yielded,

$$Q_b = 0.3 \text{ m}^3/\text{hr}$$

or by weight:

$$Q_b = 0.21 \text{ kg/s} = 0.45 \text{ lb/s}$$

This value seems quite reasonable and also it lies on the sediment rating curve developed by John Pitlick (a co-worker) for the Fall River at Horseshoe Park Bridge approximately 1 km upstream. It is therefore believed that this is a good estimate of sediment transport rate in the study reach as there were no obviously aggrading or degrading reaches between the study reach and the straight reach. A realistic confidence interval for Q_s would be ±20 percent.

*Simons, D.B., Richardson, E.V. and Nordin, C.F., 1965, "Bedload Equation for Ripples and Dunes," U.S. Geological Survey, Professional Paper 462-H, 9 p.

Two-Dimensional Velocities

x and y velocities were measured at 9 sections around the two consecutive bends (numbered zero to eight).

Each section was oriented normal to the outer bank and approximately orthogonal to the long stream direction. The current meter was set up to measure velocities normal to the section (x) and across the section (y). These were longstream (x) and cross stream (y) with reference to the local channel direction. These are not necessarily the primary and secondary components of velocity, because, especially at low flow, the primary flow may be skewed across the channel.

To account for this and resolve the resultant velocity vector at each point into its primary and secondary components a method proposed by Dietrich and Smith* was employed.

In this method, the net secondary discharge at a section (found by integrating the secondary velocity over the depth) is compared to the net secondary discharge required by continuity between the sections immediately upstream and downstream. If the two differ, the section is reoriented to change the secondary velocities until agreement is reached. The angles of reorientation were somewhat larger than expected, and are listed in Table 3.

Table 3. Angles of Reorientation of Sections

Section	1	2	3	4	5	6	7
Angle°	4.9	7	12	12.5	12.5	7.5	10

*Dietrich, W.E. and Smith, J.D., 1983, "Influence of the Point Bar on Flow in Curved Channels," Water Resources Research, paper 3W1080, Vol. 19 No. 4, October, pp. 1173-1192.

Reorienting the sections changed the y velocities significantly, although it did not radically alter the pattern of secondary flow. It is interesting to note that in all cases the net secondary discharge was vanishingly small and could have probably been taken as zero without materially altering the results. The x-y and x'-y' (primary + secondary) velocities are listed in Table 4. Primary isovels and secondary velocities are presented in Fig. 9.

The reorientation procedure could not be applied to sections 0 and 8 because the secondary discharge required could not be calculated without and upstream section for 0 and a downstream section for 8. The x and y velocities for these sections are listed in Table 5 and the longstream isovels and cross stream velocities are presented in Fig. 10.

Table 4. x-y and Primary-Secondary Velocities for Sections 1 to 7

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Velocities Secondary [m/s]
			Section 1			
0.15	0.51	0.05	-0.05	-0.04	-0.046	-0.044
		0.13	0.11	-0.03	+0.112	-0.021
		0.25	0.29	-0.03	0.291	-0.005
		0.38	0.54	-0.11	0.547	-0.063
		0.46	0.49	-0.17	0.503	-0.127
0.46	0.53	0.05	0.47	-0.002	0.478	-0.0013
		0.13	0.52	0.03	0.515	+0.076
		0.25	0.55	0.002	0.547	0.049
		0.41	0.53	-0.04	0.531	0.005
		0.48	0.49	-0.15	0.501	-0.108
0.91	0.43	0.05	0.43	-0.10	0.437	-0.063
		0.13	0.49	-0.08	0.495	-0.038
		0.20	0.50	-0.02	0.50	0.023
		0.31	0.50	+0.11	0.489	0.150
		0.38	0.55	+0.04	0.544	0.086

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
1.52	0.43	0.05	0.21	-0.08	0.216	-0.068
		0.13	0.57	-0.02	0.569	0.029
		0.20	0.54	-0.01	0.539	0.036
		0.31	0.56	0.01	0.557	0.058
		0.38	0.59	0.02	0.586	0.070
2.13	0.31	0.05	0.47	-0.05	0.472	-0.010
		0.13	0.57	-0.01	0.567	-0.058
		0.18	0.60	0.02	0.596	0.071
		0.25	0.66	0.01	0.657	0.066
3.05	0.31	0.05	0.56	0.02	0.556	0.068
		0.10	0.57	-0.03	0.570	0.019
		0.20	0.66	0.01	0.650	0.066
		0.25	0.66	0.05	0.653	0.106
4.27	0.25	0.05	0.52	-0.05	0.522	-0.054
		0.13	0.64	-0.01	0.638	0.045
		0.20	0.69	-0.04	0.691	0.019
5.49	0.20	0.05	0.54	-0.08	0.545	-0.033
		0.10	0.57	-0.06	0.573	-0.011
		0.15	0.64	-0.08	0.644	-0.025
6.70	0.23	0.05	0.55	-0.07	0.554	-0.023
		0.10	0.58	-0.13	0.589	-0.080
		0.18	0.62	-0.14	0.630	-0.86
7.92	0.23	0.05	0.42	-0.02	0.420	+0.016
		0.13	0.46	-0.05	0.462	-0.10
		0.18	0.48	-0.04	0.482	0.002
			Section 2			
0.015	0.91	0.05	0.39	-0.03	0.391	0.018
		0.15	0.30	0.01	0.296	0.046
		0.30	0.21	-0.02	0.211	0.006
		0.31	0.27	-0.02	0.270	0.013
		0.66	0.27	0.02	0.265	0.053
		0.79	0.19	0.02	0.186	0.043
		0.86	0.19	+0.01	0.187	0.029
0.46	0.94	0.05	0.42	-0.12	0.431	-0.068
		0.18	0.41	-0.13	0.423	-0.079
		0.33	0.40	-0.11	0.410	-0.060
		0.49	0.48	-0.08	0.486	-0.021
		0.85	0.53	-0.10	0.527	0.055
		0.91	0.51	-0.05	0.513	0.012

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
0.76	0.91	0.05	0.53	-0.21	0.551	-0.144
		0.15	0.53	-0.20	0.550	-0.134
		0.31	0.51	-0.14	0.523	-0.077
		0.46	0.53	-0.13	0.542	-0.064
		0.61	0.52	-0.08	0.526	-0.016
		0.79	0.54	-0.02	0.538	0.046
		0.86	0.60	-0.03	0.599	0.043
1.22	0.85	0.05	0.48	-0.18	0.498	-0.120
		0.20	0.49	-0.31	0.524	-0.248
		0.39	0.52	-0.20	0.540	-0.135
		0.76	0.52	+0.06	0.509	0.123
2.13	0.61	0.05	0.22	-0.21	+0.244	-0.180
		0.13	0.27	-0.18	0.290	-0.146
		0.28	0.51	0.02	0.504	+0.082
		0.43	0.50	0.08	0.486	0.14
		0.56	0.53	0.14	0.509	0.20
0.305	0.31	0.05	0.50	0.90	0.485	0.15
		0.18	0.58	0.13	0.560	0.20
		0.25	0.62	0.20	0.591	0.274
3.96	0.25	0.05	0.49	0.07	0.478	0.129
		0.13	0.55	0.18	0.524	0.246
		0.20	0.63	0.27	0.607	0.408
4.88	0.15	0.05	0.34	0.00	0.340	0.0
		0.10	0.24	0.05	0.232	0.079
			Section 3			
0.00	0.43					
0.31	0.46					
0.61	0.11					
0.91	0.18					
1.22	0.52					
1.52	1.10	0.06	0.07	0.02	0.670	0.028
		0.15	0.22	-0.30	0.255	-0.271
		0.33	0.38	-0.27	0.410	-0.222
		0.64	0.50	-0.20	0.521	-0.137
		0.95	0.52	0.002	0.516	0.066
		1.05	0.55	0.005	0.537	0.120

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
2.13	0.88	0.06	0.09	-0.23	0.117	-0.217
		0.15	0.21	-0.36	0.252	-0.331
		0.46	0.37	-0.09	0.378	-0.044
		0.73	0.50	0.07	0.488	0.130
		0.82	0.57	0.10	0.553	0.169
3.05	0.55	0.06	0.04	-0.03	0.433	0.025
		0.18	0.38	-0.16	0.397	-0.112
		0.40	0.51	-0.01	0.507	0.047
		0.49	0.52	-0.002	0.516	0.061
3.26	0.31	0.06	0.18	-0.01	0.179	0.012
		0.15	0.51	0.01	0.504	0.072
		0.24	0.50	0.04	0.491	0.10
4.88	0.20	0.09	0.35	-0.04	0.352	0.003
		0.15	0.43	-0.03	0.430	0.023
5.80	0.10	0.05	0.51	-0.01	0.501	0.097
6.40	0.13	0.05	0.44	0.04	0.432	0.093
		0.07	0.45	0.05	0.440	0.104
			Section 4			
0.0	0.15	--			--	
0.31	0.48	0.06	0.45	0.05	0.428	0.146
		0.15	0.47	0.02	0.454	0.12
		0.30	0.38	-0.01	0.373	0.07
		0.43	0.22	-0.12	0.241	-0.07
0.91	0.55	0.90	0.57	-0.01	0.558	0.110
		0.24	0.57	-0.05	0.567	-0.07
		0.40	0.58	-0.02	0.570	0.106
		0.49	0.59	-0.04	0.585	0.90
1.83	0.36	0.06	0.54	0.03	0.524	0.15
		0.18	0.60	-0.05	0.596	0.08
		0.30	0.60	-0.05	0.596	0.08
3.05	0.33	0.06	0.41	-0.09	0.419	0.001
		0.12	0.40	-0.12	0.416	-0.03
		0.18	0.57	-0.05	0.567	0.07
		0.27	0.61	-0.06	0.608	0.07

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
4.27	0.38	0.06	0.35	0.03	0.335	0.10
		0.15	0.44	-0.02	0.434	0.07
		0.23	0.46	-0.03	0.456	0.07
		0.32	0.53	-0.05	0.528	0.06
5.18	0.33	0.06	0.20	0.02	0.191	0.06
		0.18	0.52	-0.03	0.514	0.08
		0.27	0.52	-0.02	0.512	0.09
5.18	0.33	0.06	0.20	0.02	0.191	0.06
		0.18	0.52	-0.03	0.514	0.08
		0.27	0.52	-0.02	0.512	0.09
6.10	0.27	0.06	0.33	0.004	0.321	0.075
		0.12	0.39	-0.05	0.391	0.035
		0.21	0.49	-0.08	0.496	0.027
7.31	0.27	0.06	0.22	-0.06	0.228	-0.011
		0.12	0.27	-0.07	0.279	-0.010
		0.21	0.28	-0.08	0.291	-0.017
			Section 5			
0.31	0.06	--				
0.61	0.11	--				
0.91	0.14	0.06	0.36	-0.12	0.363	-0.90
		0.12	0.41	-0.16	0.422	-0.124
1.83	0.15	0.06	0.43	-0.20	0.445	-0.162
		0.12	0.46	-0.25	0.480	-0.20
2.74	0.18	0.06	0.33	-0.28	0.353	-0.25
		0.12	0.41	-0.23	0.428	-0.193
		0.15	0.48	-0.24	0.499	-0.197
3.66	0.18	0.06	0.46	-0.26	0.481	-0.219
		0.12	0.50	-0.27	0.522	-0.225
4.88	0.26	0.06	0.45	-0.26	0.471	-0.219
		0.15	0.53	-0.23	0.548	-0.183
		0.23	0.49	-0.26	0.511	-0.216
6.10	0.33	0.06	0.16	-0.002	0.159	+0.012
		0.15	0.45	-0.13	0.459	-0.09
		0.31	0.49	-0.16	0.502	-0.117

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
7.00	0.46	0.06	0.12	0.11	0.110	0.12
		0.15	0.25	0.12	0.239	0.14
		0.31	0.48	-0.08	0.485	-0.037
		0.43	0.52	-0.19	0.534	-0.144
7.92	0.70	0.06	0.14	0.07	0.133	0.082
		0.15	0.24	0.19	0.222	0.21
		0.31	0.30	0.10	0.290	0.125
		0.46	0.33	0.05	0.324	0.078
		0.61	0.36	-0.07	0.365	-0.038
		0.67	0.38	-0.10	0.388	-0.066
8.84	0.82	0.06	0.17	0.13	-0.158	0.144
		0.18	0.25	0.20	0.233	0.22
		0.36	0.30	0.15	0.322	0.175
		0.49	0.30	0.06	0.294	0.086
		0.64	0.33	-0.03	0.331	0.001
		0.76	0.37	-0.10	0.377	-0.067
9.45	0.52	0.06	0.10	0.03	0.097	0.039
		0.17	0.30	0.18	0.283	0.205
		0.31	0.30	0.14	0.286	0.165
		0.43	0.34	0.05	0.334	0.079
			Section 6			
0.31	0.03					
0.61	0.03					
0.91	0.05					
1.22	0.05					
1.52	0.06					
1.83	0.09					
2.13	0.12	0.06	0.52	-0.08	0.505	-0.148
		0.09	0.31	-0.16	0.286	-0.200
3.05	0.15	0.06	0.43	-0.09	0.414	-0.146
		0.07	0.45	-0.11	0.432	-0.168
		0.12	0.47	-0.15	0.446	-0.210
3.66	0.18	0.06	0.46	-0.07	0.447	-0.13
		0.11	0.47	-0.27	0.437	-0.343
		0.15	0.47	-0.20	0.440	-0.260

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
3.96	0.31	0.06	0.31	-0.03	0.303	-0.071
		0.15	0.36	-0.03	0.353	-0.077
		0.24	0.38	-0.08	0.366	-0.129
4.27	0.46	0.06	0.07	0.08	0.080	0.070
		0.15	0.26	0.02	0.260	-0.014
		0.31	0.35	-0.04	0.342	-0.086
		0.40	0.38	-0.08	0.366	-0.129
4.57	0.58	0.06	0.14	0.13	0.156	0.110
		0.15	0.22	0.20	0.244	0.169
		0.31	0.35	0.06	0.352	0.013
		0.43	0.41	-0.03	0.402	-0.084
		0.52	0.40	-0.06	0.389	-0.112
5.18	0.85	0.06	0.14	0.18	0.162	0.160
		0.15	0.23	0.25	0.261	0.217
		0.36	0.34	0.21	0.364	0.163
		0.61	0.36	0.06	0.349	0.012
		0.79	0.40	-0.06	0.388	-0.112
6.10	1.31	0.06	-0.02	0.20	-0.008	0.20
		0.18	0.06	0.23	0.089	0.22
		0.31	0.22	0.22	0.247	0.189
		0.61	0.35	0.16	0.368	0.112
		0.97	0.49	-0.03	0.482	-0.094
		0.122	0.51	-0.04	0.500	-0.107
7.00	0.82	0.06	0.37	0.05	0.363	0.001
		0.15	0.40	0.07	0.406	0.017
		0.46	0.52	0.02	0.518	-0.049
		0.67	0.50	-0.05	0.489	-0.115
		0.76	0.53	-0.15	0.506	-0.218
7.62	0.61	0.06	0.25	0.06	0.257	0.026
		0.18	0.32	0.09	0.329	0.047
		0.31	0.44	0.07	0.445	0.011
		0.46	0.50	0.01	0.497	-0.056
		0.55	0.51	0.02	0.509	-0.047
7.92	0.40	0.06	0.05	0.01	0.051	0.003
		0.12	0.14	0.01	0.140	-0.009
		0.24	0.17	0.06	0.176	0.037
		0.33	0.25	0.12	0.263	0.086

Table 4. (continued)

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities x [m/s]	y [m/s]	Modified Primary [m/s]	Secondary [m/s]
			Section 7			
0.31	0.11					
0.61	0.14					
0.91	0.15	0.06	0.32	0.11	0.334	0.053
		0.11	0.33	0.07	0.337	0.011
1.83	0.21	0.06	0.36	0.04	0.361	-0.023
		0.15	0.41	0.01	0.405	-0.061
2.74	0.31	0.06	0.53	-0.03	0.517	-0.121
		0.18	0.54	-0.02	0.528	-0.113
		0.24	0.52	-0.02	0.509	-0.110
3.35	0.55	0.06	0.29	0.06	0.296	0.009
		0.18	0.47	0.02	0.467	-0.062
		0.31	0.53	-0.001	0.522	-0.093
		0.49	0.54	0.02	0.535	-0.074
4.27	0.61	0.06	0.46	0.07	0.465	-0.011
		0.18	0.59	0.08	0.595	-0.024
		0.31	0.60	0.04	0.598	-0.065
		0.46	0.58	-0.01	0.569	-0.110
		0.55	0.59	-0.02	0.584	0.082
4.88	0.82	0.06	0.37	0.16	0.392	0.093
		0.18	0.57	0.02	0.564	-0.079
		0.40	0.58	0.04	0.578	-0.061
		0.61	0.56	0.09	0.567	-0.008
		0.73	0.53	0.12	0.542	0.026
5.18	0.88	0.06	0.43	0.06	0.433	-0.16
		0.18	0.54	-0.01	0.530	-0.104
		0.43	0.60	0.01	0.608	-0.001
		0.67	0.57	0.08	0.575	-0.020
		0.82	0.56	0.15	0.577	0.050
5.48	0.76	0.18	0.04	0.05	0.481	0.042
		0.36	0.52	0.03	0.517	-0.061
		0.67	0.45	0.16	0.471	0.097

Table 5. x-y Velocities for Sections 0 and 8

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities V_x [m/s]	Measured Velocities V_y [m/s]
		Section 0		
1.83	0.13	0.05	0.23	0.02
		0.10	0.26	0.03
3.35	0.33	0.05	0.33	0.13
		0.10	0.35	0.11
		0.20	0.37	0.12
		0.20	0.37	0.12
		0.30	0.33	0.11
4.57	0.51	0.05	0.38	0.13
		0.12	0.38	0.07
		0.25	0.42	0.10
		0.38	0.41	0.13
		0.46	0.42	0.11
5.18	0.51	0.05	0.40	0.04
		0.13	0.44	0.06
		0.25	0.54	0.16
		0.38	0.56	0.18
		0.46	0.52	0.20
0.580	0.48	0.05	0.44	0.02
		0.13	0.53	0.07
		0.23	0.56	0.16
		0.35	0.58	0.17
		0.43	0.59	0.18
6.40	0.50	0.05	0.40	0.06
		0.13	0.45	0.04
		0.25	0.57	0.13
		0.35	0.53	0.12
		0.43	0.52	0.10
		0.50	0.53	0.10
7.00	0.51	0.46	0.57	0.11
		0.38	0.54	0.06
		0.25	0.55	0.05
		0.13	0.61	0.09
		0.05	0.42	-0.003
7.62	0.41	0.35	0.57	0.12
		0.28	0.58	0.05
		0.15	0.62	0.04
		0.05	0.42	-0.18

Table 5. Continued.

Distance from bank [m]	Total depth [m]	Height above bed [m]	Measured Velocities V_x [m/s]	Measured Velocities V_y [m/s]
8.53	0.23	0.18	0.49	-0.11
		0.13	0.53	-0.16
		0.05	0.53	-0.08
		Section 8		
0.31	0.00			
0.61	0.18	0.06	0.02	-0.004
		0.12	0.03	0.03
0.91	0.24			
1.22	0.31	0.06	0.05	-0.003
		0.18	0.13	0.04
		0.24	0.14	0.04
2.13	0.24	0.09	0.33	0.11
		0.18	0.33	0.10
3.05	0.30	0.06	0.37	-0.02
		0.12	0.36	0.05
		0.21	0.35	0.12
3.96	0.36	0.06	0.46	0.07
		0.18	0.61	0.20
		0.31	0.63	0.22
4.88	0.40	0.06	0.47	0.25
		0.15	0.53	0.24
		0.24	0.59	0.14
		0.33	0.62	0.12
5.80	0.36	0.06	0.48	0.17
		0.15	0.60	0.19
		0.31	0.60	0.15
6.40	0.40	0.06	0.62	0.10
		0.18	0.60	0.09
		0.31	0.55	0.13
7.31	0.33	0.06	0.35	0.20
		0.15	0.43	0.12
		0.27	0.50	0.05
8.23	0.21	0.09	0.39	0.13
		0.17	0.48	0.06
9.14	0.15	0.06	0.24	0.04
		0.11	0.31	-0.02

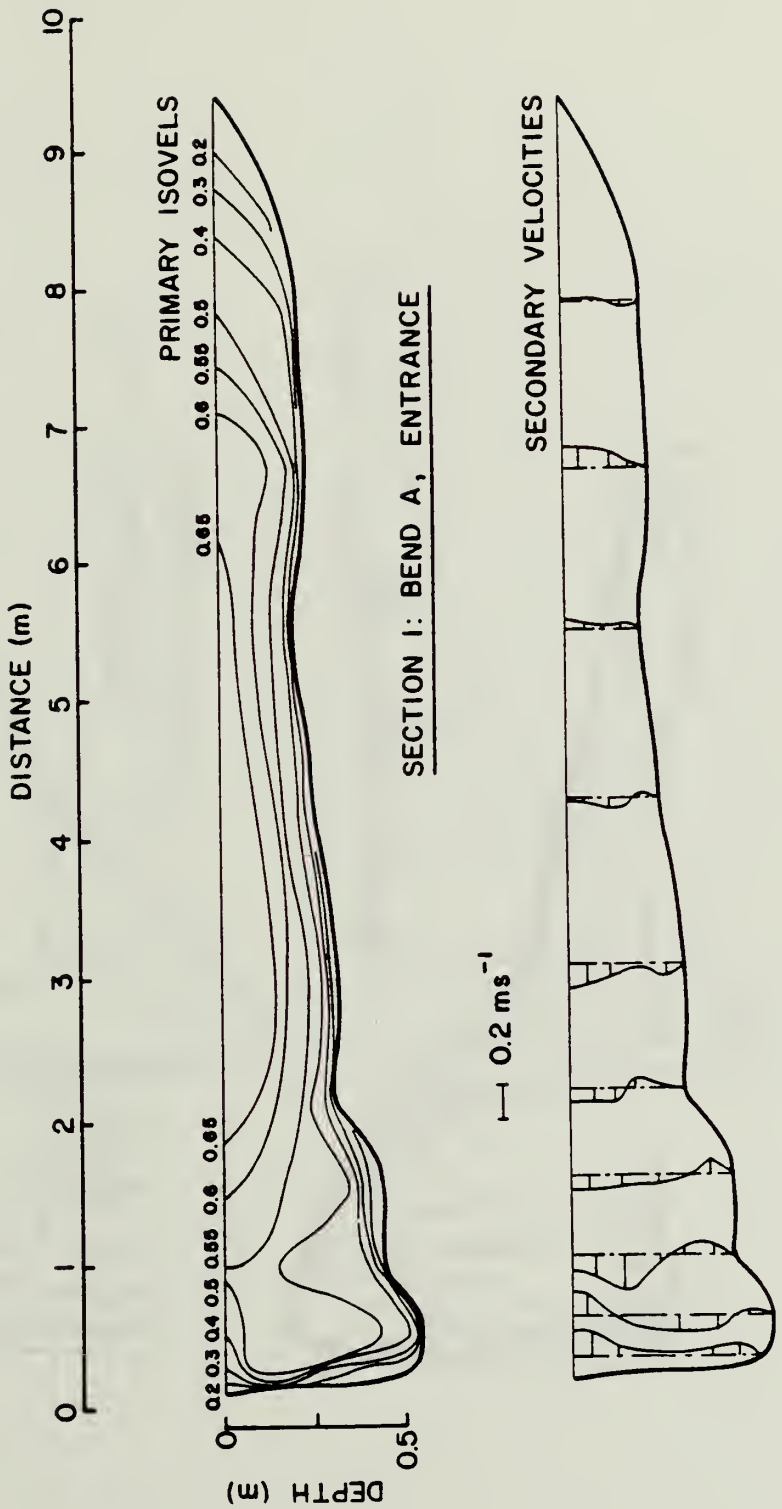

Figure 9. Primary Isovels and Secondary Velocities at Section 1

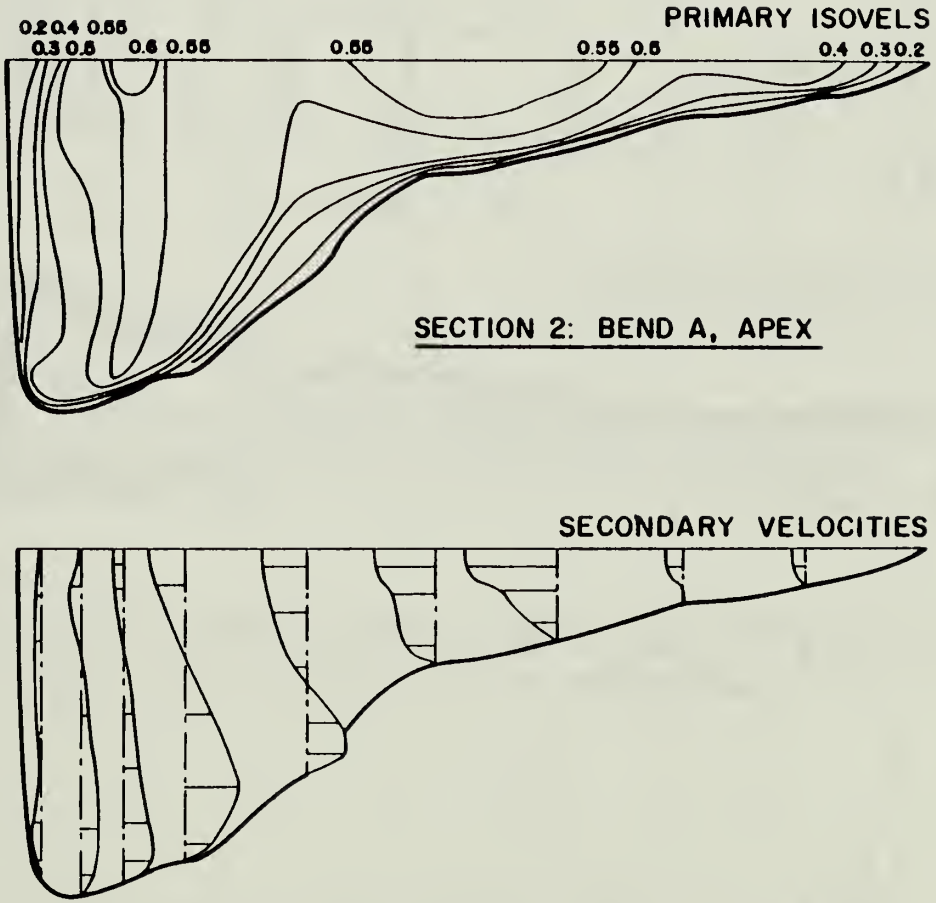

Figure 9. Primary Isovels and Secondary Velocities at Section 2

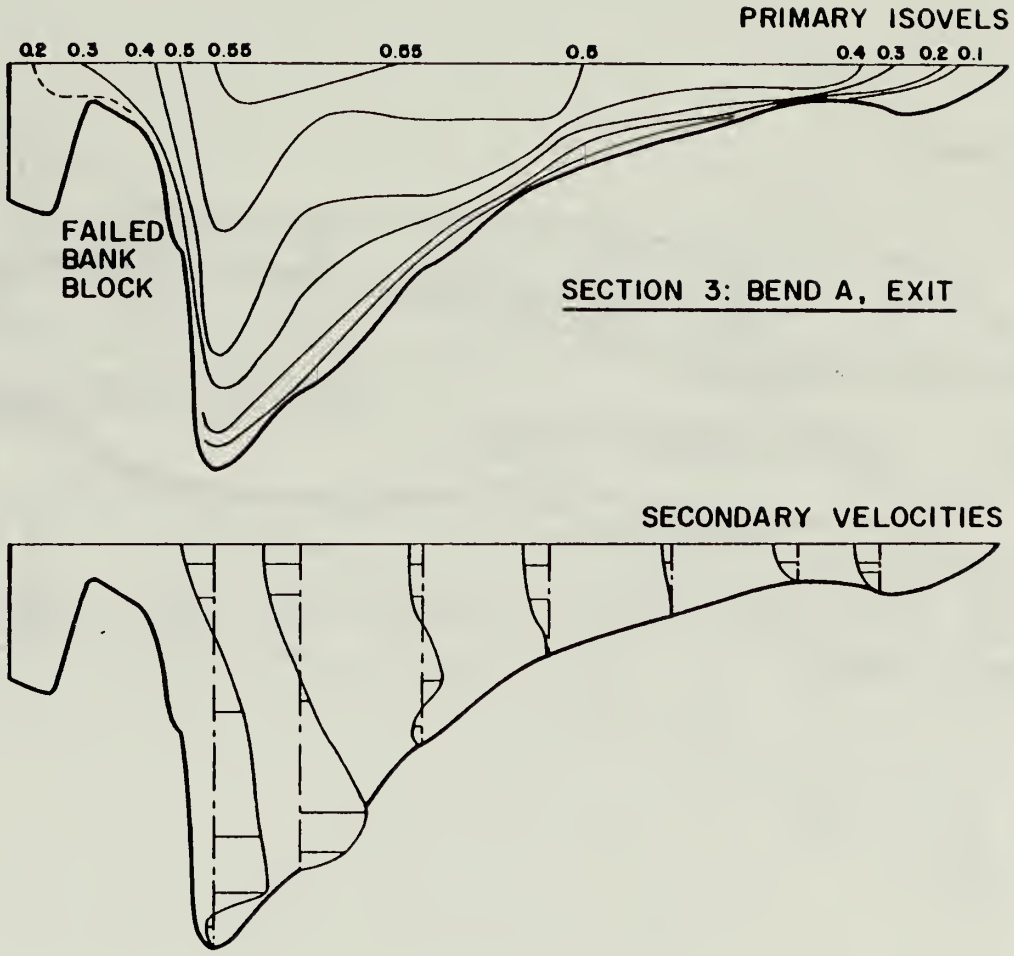

Figure 9. Primary Isovels and Secondary Velocities at Section 3

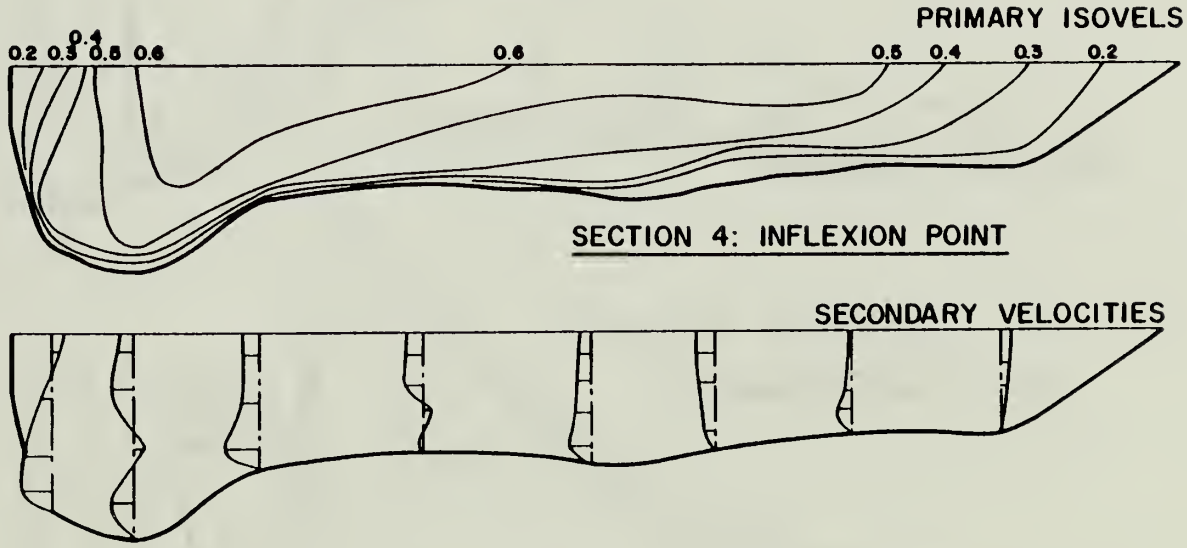

Figure 9. Primary Isovels and Secondary Velocities at Section 4

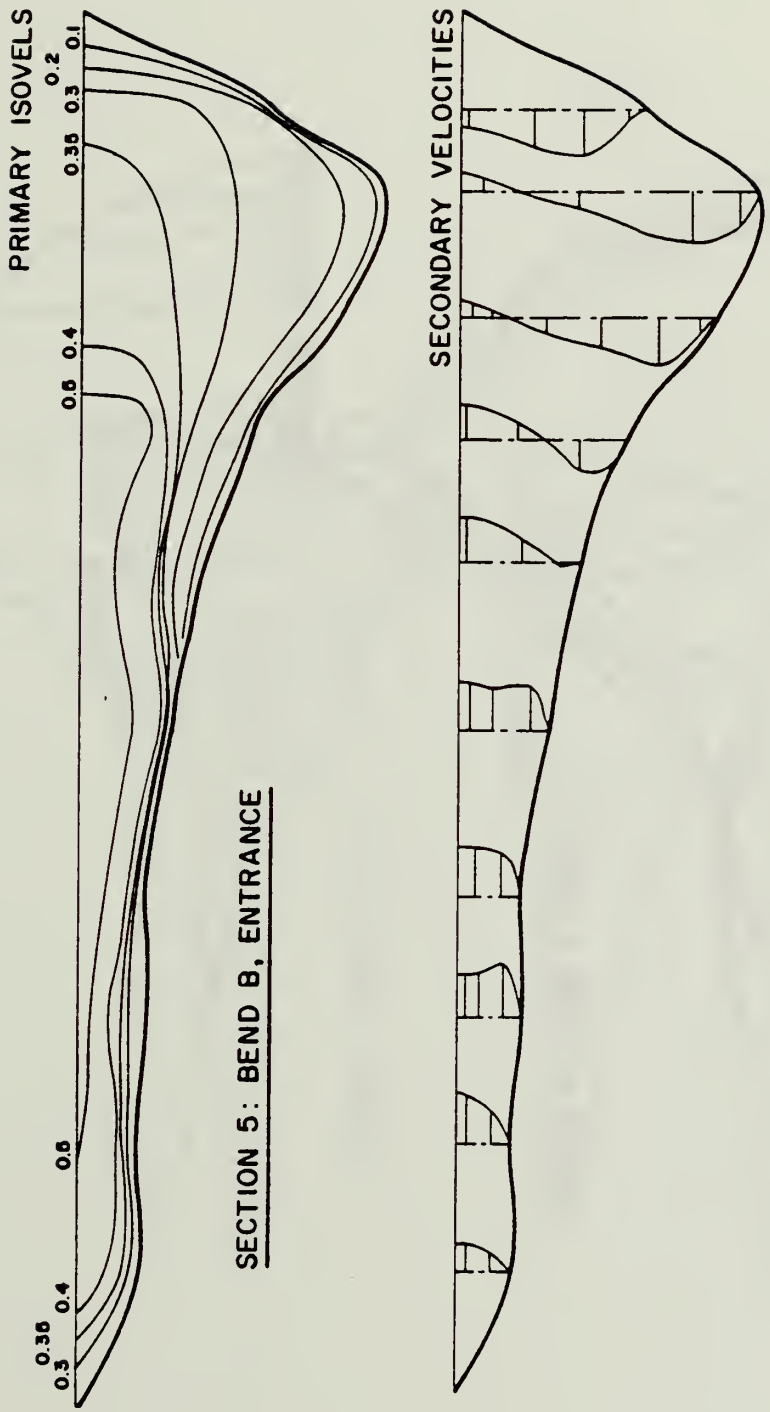

Figure 9. Primary Isovels and Secondary Velocities at Section 5

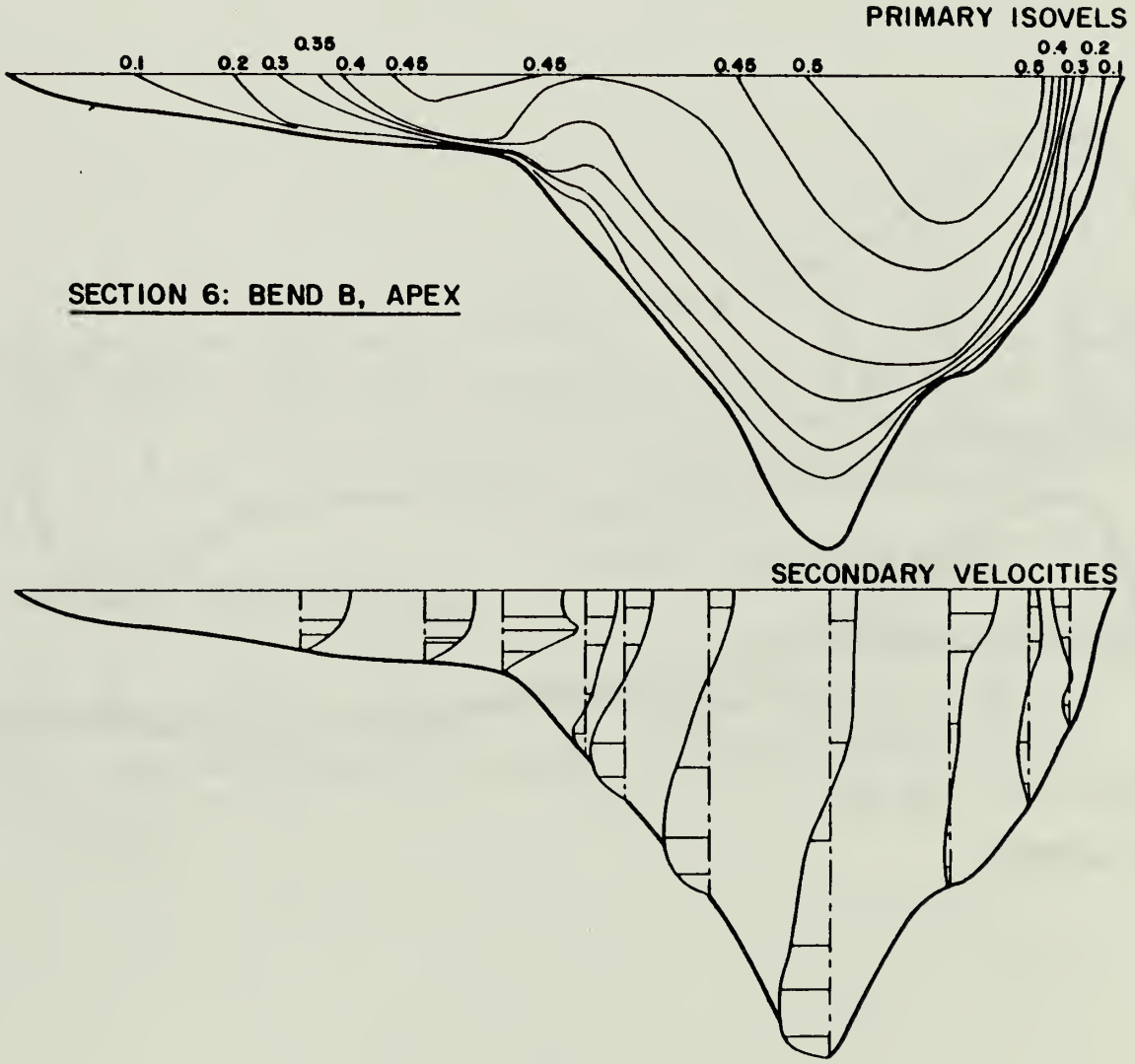

Figure 9. Primary Isovels and Secondary Velocities at Section 6

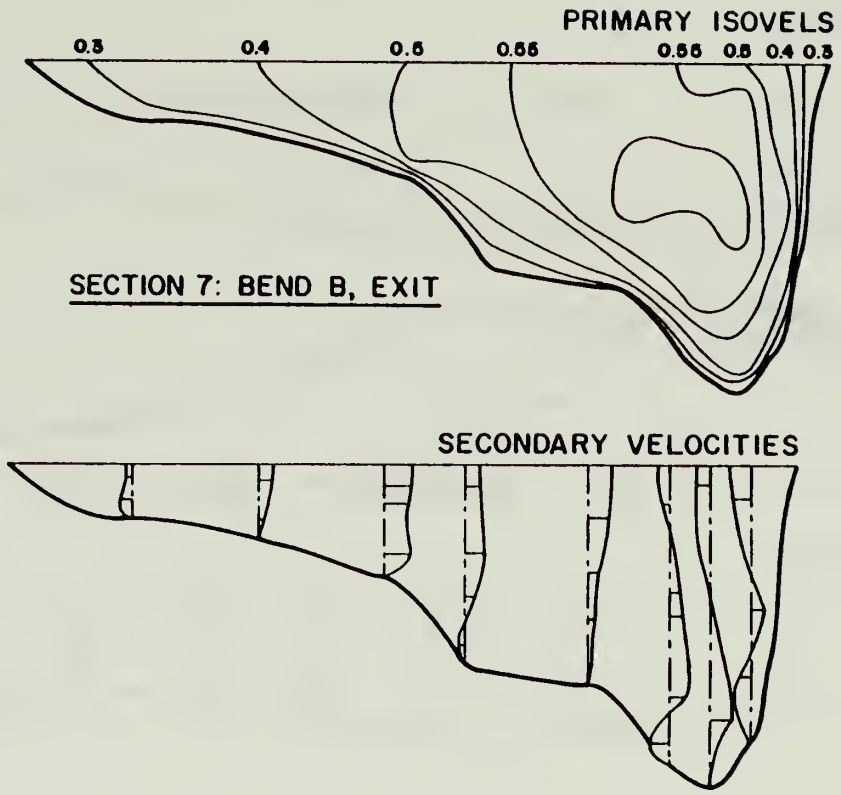

Figure 9. Primary Isovels and Secondary Velocities at Section 7

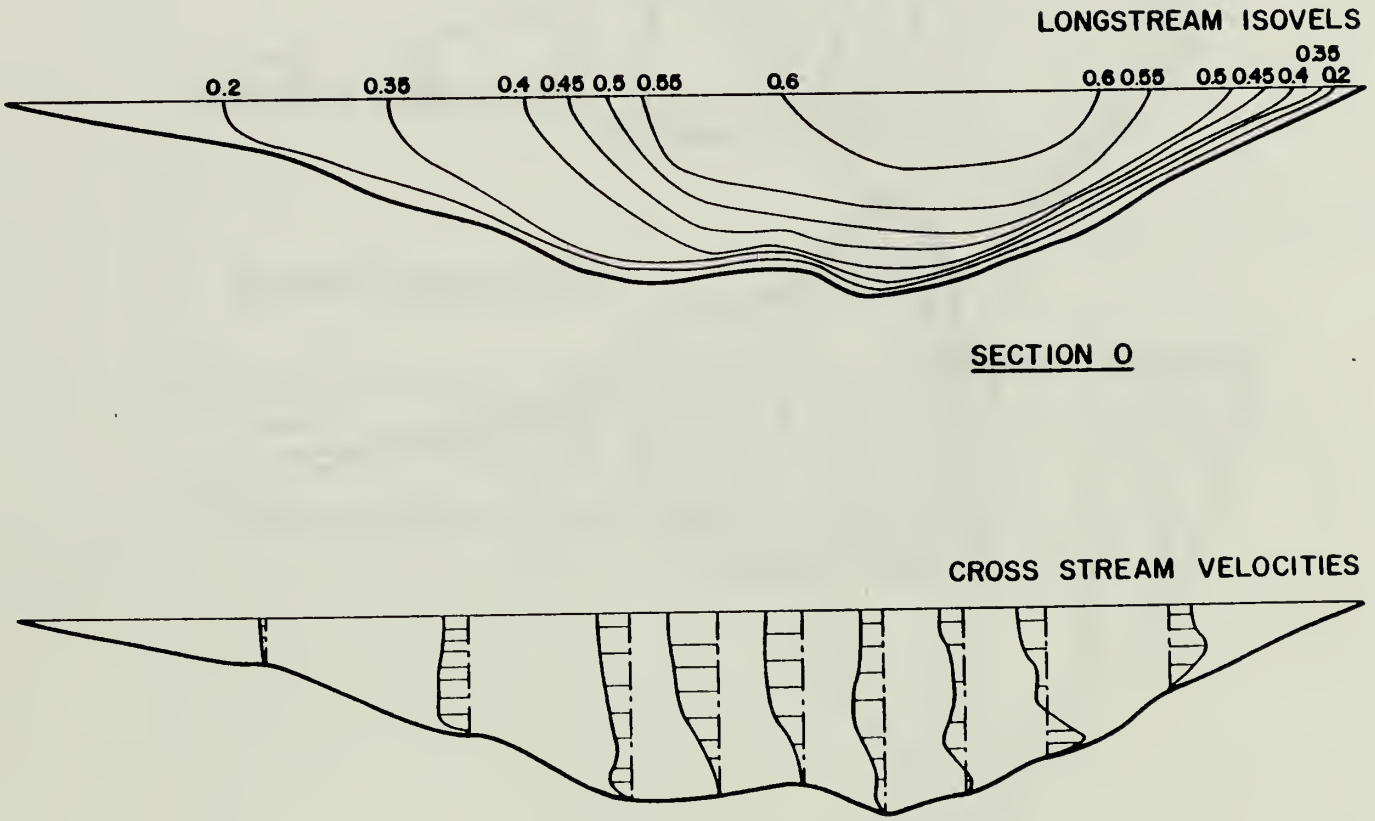

Figure 10. Long Stream and Cross Stream Velocities at Section 0

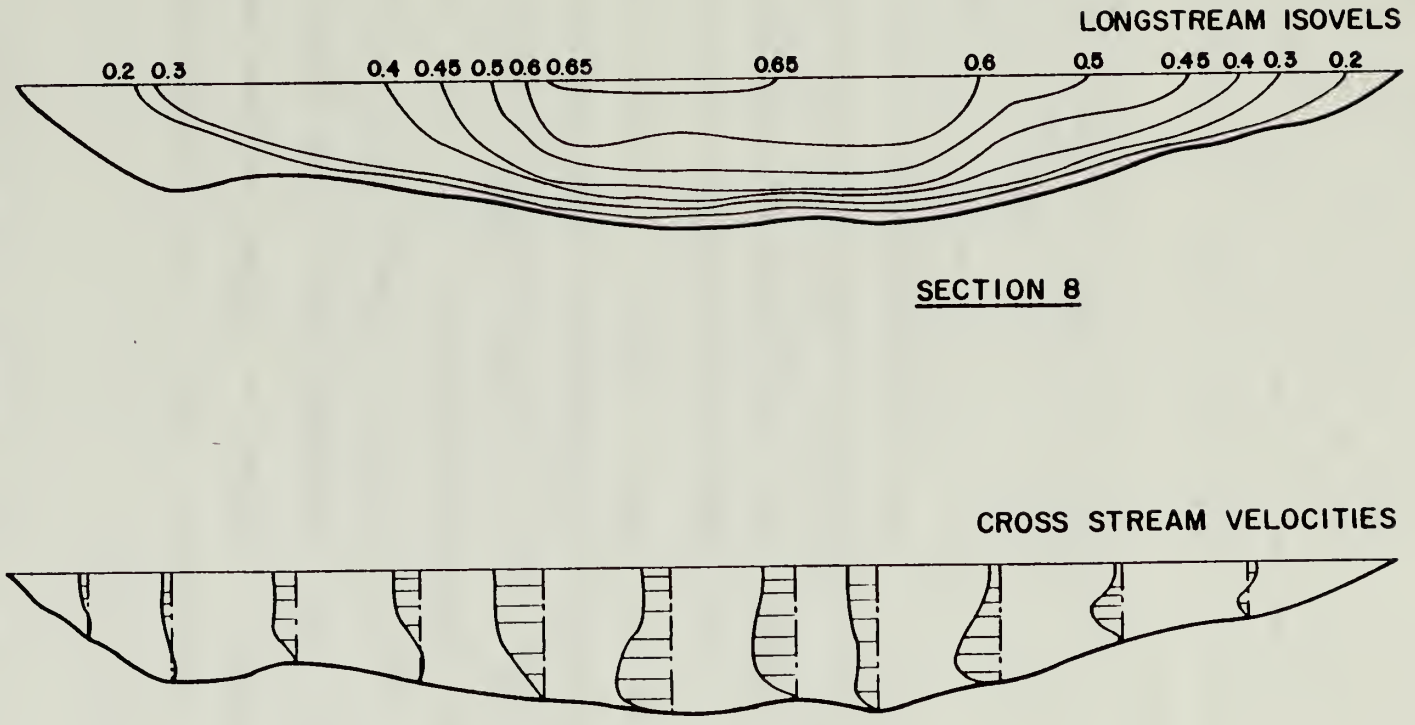

Figure 10. Long Stream and Cross Stream Velocities at Section 8

CONCLUSIONS

The data recorded here are internally consistent and bear striking resemblance to data from similar river bends under similar flow conditions. They were collected carefully and with the best accuracy possible given the instrumentation available. Consequently, it is concluded that the data are a reliable facsimilie of flow patterns and sediment distribitions in bends of the Fall River on August 24-27th, 1983.

The question still remains, are these bends representative of river bends in sand bed rivers in general? The evidence is that they are.

In terms of planform characteristics, the data in Table 1 show radius of curvature to average width values 1.41 and 1.67 for bends A and B, respectively. Comparison to Hey's relationship for radius of curvature, width and arc angle for natural meanders shows these values to be very close to those expected.* The channel cross sections show both the symmetry expected at inflexion points and the asymmetry expected at bend sections. There is also a well developed "point bar face" as noted in channels transporting high sand load, by Dietrich and Smith (see ref. on page 27).

The bed material is mostly log normal or bimodal in distribution. Its areal distribution again looks similar to that found in other studies. Bedforms are ripples and dunes depending on local hydraulic conditions, with areas of gravel exposed where the flow has stripped away the sand.

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*R.D. Hey, 1976, "Geometry of River Meanders," NATURE, Vol. 262, pp. 482-484.

The primary and secondary velocity measurements confirm the results of previous investigations. At a bend the pattern is dominated by a skew-induced helical circulation carrying surface water outwards and bed water inwards. At the outer bank there is often a small cell of reverse rotation caused by interaction of the main helical flow with the bank. At the inner bank secondary flow over the point bar surface is radially outwards, leading to strong near bed flow convergence at the point bar face crest.

In conclusion, the authors believe that the data presented here are reliable and may be used to test bend flow models for sand-bedded meandering rivers.

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